Study of the decays of the Higgs boson to boson pairs at Run-II with the ATLAS experiment

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Summary. — The Higgs boson plays an important role in the Standard Model: it provides mass to the elementary particles through the electroweak spontaneous symmetry breaking (EWSB). Discovered in 2012 by the ATLAS and CMS Collaborations, today the Higgs boson is a very powerful tool to test the validity of SM theory at the TeV scale. The Higgs boson can be produced at proton-proton colliders, such as LHC, in different ways and many decay channels are predicted by the Standard Model. At ATLAS Run-2, this particle is widely studied mainly through its decays in vectors boson pairs ($H \to ZZ^*$, $H \to WW^*$ and $H \to \gamma\gamma$). In this context, the latest results, obtained using the dataset collected by the ATLAS experiment during 2015 and 2016 at a center-of-mass energy of 13 TeV, are presented. Experimental techniques and estimates of the main backgrounds will be discussed in detail.

1. – $H \to WW^*$ analysis

The Higgs boson search in the $H \to WW^* \to \ell\nu\ell\nu$ (where ℓ denotes an electron or a muon) decay mode has been performed during ATLAS Run-2 exploiting an integrated luminosity of $5.8\,\mathrm{fb}^{-1}$ [1]. The analysis is restricted to two distinctive production modes: the Vector Boson Fusion (VBF) and the associated production of the Higgs boson with a W boson (WH).

In the VBF analysis, two leptons with different flavours are required, in order to reject the Drell-Yan background, as well as two jets at large pseudo-rapidity characterizing the VBF event topology. The WH analysis selects events with three leptons having total electric charge of $\pm e$. Here, events are further divided into two categories according to the number of same-flavour and opposite-sign lepton pairs. In order to fully exploit the correlations among various discriminating variables, a multivariate analysis with a Boosted Decision Tree (BDT) is developed for the VBF analysis.

For both channels, the background normalization is estimated from data using appropriate Control Regions. Finally, the Signal and Control Regions are fit together to extract the background Normalization Factors and the signal strength.

In each production channel analysis, events from all other Higgs production mechanisms are treated as background. For these processes, Standard Model (SM) cross-sections, branching fractions and acceptances for $m_H = 125\,\text{GeV}$ are assumed.

The fit results for the signal strength for the VBF and WH production modes are found to be

- $\mu_{VBF} = 1.7^{+1.0}_{-0.8}(\text{stat.})^{+0.6}_{-0.4}(\text{syst.})$;

- $\mu_{WH} = 3.2^{+3.7}_{-3.2}(\text{stat.})^{+2.3}_{-2.7}(\text{syst.})$.

Assuming the background-only hypothesis, the corresponding observed (expected) significances are 1.9σ (1.2σ) and 0.8σ $(0.2\sigma$ exp$)$ for the VBF and WH analyses, respectively.

2. – $H \to ZZ^* \to 4\ell$ analysis

The dataset used in the $H \to ZZ^* \to 4\ell$ search consists of $14.8\,\text{fb}^{-1}$ of data collected at a center-of-mass energy of $13\,\text{TeV}$ [2]. This channel offers a high resolution on the Higgs mass and a good signal/background ratio (about a factor 2 in the Higgs mass window). The only main relevant background is the non-resonant ZZ^* background and it is estimated from MC simulations.

The fiducial cross-section, extracted from events in the mass region $115 < m(4\ell) < 130\,\text{GeV}$, is found to be $\sigma^{4\ell}_{fid,sum} = 4.48^{+1.01}_{-0.89}\,\text{fb}$, in agreement with the SM expectation $\sigma^{4\ell}_{fid,SM} = 3.07^{+0.21}_{-0.25}\,\text{fb}$.

Moreover, an event categorization is performed using multivariate analysis techniques (based on BDTs) and used to distinguish among different production modes. The measured total cross-sections for each production mode are reported below:

- $\sigma_{ggF+bbH+ttH} \cdot B(H \to ZZ^*) = 1.80^{+0.49}_{-0.44}\,\text{pb}$;

- $\sigma_{VBF} \cdot B(H \to ZZ^*) = 0.37^{+0.28}_{-0.21}\,\text{pb}$;

- $\sigma_{VH} \cdot B(H \to ZZ^*) = 0.00^{+0.15}\,\text{pb}$.

The SM predictions are in good agreement with the experimental results.

3. – $H \to \gamma\gamma$ analysis

The Higgs boson search in the $H \to \gamma\gamma$ decay mode has been performed during ATLAS Run-2 exploiting an integrated luminosity of $13.3\,\text{fb}^{-1}$ [3]. This channel offers a clean experimental signature and good invariant-mass resolution.

The search is performed exploiting all the Higgs production mode categories. The signal yield is extracted from a simultaneous signal+background fit to the diphoton invariant-mass distribution. The non-resonant diphoton continuum background, consisting of $\gamma\gamma$, γ-jet, jet-jet events, is estimated from data using dedicated Control Regions, defined reversing the isolation and identification requirements of the photons.

The fiducial cross-section is measured in a variety of phase space regions. The cross-section measured in the baseline [3] fiducial region is found to be $\sigma_{fid} = 43.2 \pm 14.9(\text{stat.}) \pm 4.9(\text{syst.})\,\text{fb}$. The Standard Model prediction for the same fiducial region is $\sigma_{fid} = 62.8^{+3.4}_{-4.4}\,\text{fb}$, in agreement with the experimental result.

The total production cross-section is measured independently for different Higgs production modes and for their combination. The combined signal strength is found to be $\mu = 0.85^{+0.22}_{-0.20}$, leading to an observed significance of 4.7σ (expected significance 5.4σ). This result is compatible with the Run-1 value of $\mu = 1.17^{+0.28}_{-0.26}$.
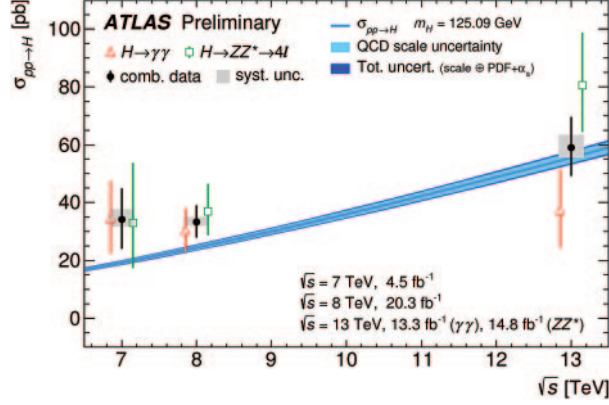
Fig. 1. – $pp \rightarrow H + X$ fiducial cross-sections measured at different centre-of-mass energies, compared to Standard Model predictions at up to N3LO in QCD [4].

4. – $H \rightarrow ZZ^* \rightarrow 4\ell$ and $H \rightarrow \gamma\gamma$ combination

The combination of the total cross-section measurements, obtained in the $H \rightarrow ZZ^* \rightarrow 4\ell$ and $H \rightarrow \gamma\gamma$ analysis described above, has been performed [4]. No attempt is made to disentangle the different Higgs boson production modes.

The analysis is performed to measure the fiducial cross-section of $pp \rightarrow H + X$. The event yields measured in the two channels are corrected for detector effects, fiducial acceptances and branching ratios. The total fiducial cross-section is found to be $\sigma_{fid} = 59.0^{+9.7}_{-9.2}(\text{stat.})^{+4.4}_{-3.5}(\text{syst.})$ pb. The comparison with the SM expectation leads to a global signal strength of $\mu = 1.17^{+0.18}_{-0.17}$.

Using also previous measurements at 7 and 8 TeV, the centre-of-mass energy dependence of the total Higgs production cross-section is compared to theoretical predictions up to N3LO in QCD. The trend of the $pp \rightarrow H + X$ fiducial cross-section as a function of the centre-of-mass energy is shown in fig. 1. No significant deviations from the Standard Model predictions are observed.

REFERENCES

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[4] ATLAS COLLABORATION, ATLAS-CONF-2016-81, *Combined measurements of the Higgs boson production and decay rates in $H \rightarrow ZZ^* \rightarrow 4\ell$ and $H \rightarrow \gamma\gamma$ final states using pp collision data at $\sqrt{s} = 13$ TeV in the ATLAS experiment*.