PROCEEDINGS OF SCIENCE

Measurement of production cross sections of the Higgs boson in decays to two W bosons using the ATLAS detector

Dominik Duda, on behalf of the ATLAS collaboration
Max-Planck-Institut fuer Physik, Germany
E-mail: dominik.duda@cern.ch

This proceedings presents the latest measurements of the Higgs boson production cross sections times branching ratio in the $H \to WW^* \to \ell\nu\ell\nu$ decay mode for the three most dominant production processes of the Higgs boson: gluon-gluon fusion, vector boson fusion and the associated production of a vector boson and a Higgs boson. The measurements are performed based on proton-proton collision data collected at 13 TeV by the ATLAS detector. The cross section times branching ratios of the gluon-gluon fusion and vector boson fusion production modes are measured in a dataset corresponding to an integrated luminosity of $36.1\,\mathrm{fb}^{-1}$ and are found to be $12.6^{+1.3}_{-1.2}(stat.)^{+1.9}_{-1.8}(sys.)$ pb and $0.5^{+0.24}_{-0.23}(stat.) \pm 0.18(sys.)$ pb, respectively. The cross section times branching ratio of the associated production of a vector boson and a Higgs boson is measured in a dataset corresponding to an integrated luminosity of $5.8\,\mathrm{fb}^{-1}$ and is found to be $0.9^{+1.1}_{-0.9}(stat.)^{+0.7}_{-0.8}(sys.)$ pb. For all three production modes, the measured cross section times branching ratio are compatible to the SM predictions within one standard deviation.

The 39th International Conference on High Energy Physics (ICHEP2018)
4-11 July, 2018
Seoul, Korea

PoS(ICHEP2018)221

The discovery of the Higgs boson in 2012 was the greatest success of the LHC experiments so far. Measurements of its properties are consistent with the Standard Model (SM) predictions. The Higgs boson mass was measured by ATLAS and CMS to be $m_H = 125.09 \pm 0.21(stat) \pm 0.11(syst)$, while the Spin and CP state of the Higgs boson, determined by probing angular distribustion of its decay products, hints very strongly to a $\mathrm{Spin}^{\mathrm{CP}}$ state of 0^+. Still, measurements of the Higgs boson properties remain to be of great interest as they are very sensitive to the presence of new phyiscs.

The $H \to WW^* \to \ell\nu\ell\nu$ decay channel has the second largest branching fraction and a relatively clear signature in the detector. Thus it allows for precise measurements of Higgs boson properties.

Due to the spin-0 nature of the Higgs boson and the V-A structure of the subsequent W boson decays, this decay channel is characterised by two oppositely charged leptons with a small opening angle and a relatively small invariant mass $m_{\ell\ell}$. The presence of at least two high energetic neutrinos in the targeted final state prevents the full reconstruction of the four-vector of the Higgs boson and thus its invariant mass. However, the transverse mass m_{T} of the Higgs boson can be calculated via $m_{\mathrm{T}} = \sqrt{(E_{\ell\ell} + E_{\mathrm{T}}^{\mathrm{miss}})^2 - |p_{\mathrm{T},\ell\ell} + E_{\mathrm{T}}^{\mathrm{miss}}|^2}$, with $E_{\ell\ell} = \sqrt{|p_{\mathrm{T},\ell\ell}|^2 + m_{\ell\ell}^2}$ as well as $E_{\mathrm{T}}^{\mathrm{miss}}$ and $p_{\mathrm{T},\ell\ell}$, which are the missing transverse momentum and the combined dilepton four-vector in the transverse plane, respectively.

In this proceedings, the latest measurements of the Higgs boson production cross sections in the $H \to WW^* \to \ell\nu\ell\nu$ decay mode are presented for the three most dominant production modes of the Higgs boson: gluon-gluon fusion, ggF (86%), vector boson fusion, VBF (7%), and the associated production of a vector boson and a Higgs boson, VH (5%). Exemplary Feynman diagrams for these processes are presented in Figure 1.

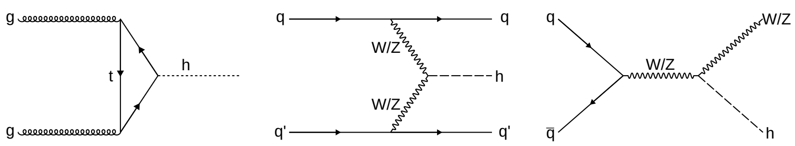

Figure 1: Exemplary Feynman diagrams of the ggF (left), VBF (middle) and VH (right) production modes of the Higgs boson at tree-level.

The latest measurements of the ggF and VBF Higgs boson production cross-sections are preformed in the $H \to WW^* \to \ell\nu\ell\nu$ decay mode using a dataset that has been recorded by the ATLAS detector [1] in the 2015 and 2016 runs of the LHC. This dataset was taken during proton-proton collisions at a centre-of-mass energy of 13 TeV and corresponds to an integrated luminosity of $36.1\,\mathrm{fb}^{-1}$.

Selected $H \to WW^* \to \ell\nu\ell\nu$ candidate events are classified according to their multiplicity of jets[1] N^{jets} with a transverse momentum p_{T} larger than 30 GeV and with an absolute value of the pseudo-rapidity $|\eta|$ smaller than 4.5. Event categories with $N^{\mathrm{jets}} = 0$ and $N^{\mathrm{jets}} = 1$ are defined in order to target the ggF production mode, while a $N^{\mathrm{jets}} \geq 2$ category is used for measurements in the VBF production mode. Topology specific variables such as the invariant mass and the rapidity gap of the dijet system are used as inputs for a boosted decision tree (BDT), which allows to further enhance the VBF signal with respect to the sum of backgrounds.

[1] Jets correspond to hadronic particle showers that are reconstructed from topological clusters of energy deposits in the calorimeter system using the anti-k_T algorithm with a distance parameter of $R = 0.4$.

Dedicated control regions are defined in order to constrain the normalisations of the most dominant background processes (WW, $t\bar{t}+Wt$ and $Z\gamma^{*}+$ jets), while smaller backgrounds such as WZ, ZZ or $W\gamma$ are entirely taken from the simulation. In order to estimate the contributions from background processes containing mis-identified leptons, a control sample is defined using events with one well-defined lepton and one lepton failing nominal object definitions requirements but passing looser requirements (referred to as anti-identified). The contribution of the mis-identified lepton background to the signal region is estimated by scaling the control sample via p_{T} and η dependent extrapolation factors, which are defined as the ratio of the well-defined leptons to anti-identified leptons.

The cross sections for the ggF and VBF production modes are obtained by a simultanious fit to the various control and signal regions maximising a likelihood function. The fit is performed on the transverse mass m_{T} for the $N^{\mathrm{jets}}=0$ and $N^{\mathrm{jets}}=1$ categories, while in the VBF category the score of the boosted decision tree is used. Data-to-simulation comparison of both these distributions are depicted in Figure 2. The ggF production mode is profiled while the significance of the VBF production mode is determined, and vice-versa. Systematic uncertainties enter the likelihood function as nuisance parameters. The most dominant uncertainties are related to the modelling of the various background processes ($\pm8\%$ in ggF and $\pm21\%$ VBF), the data statistics ($\pm8\%$ in ggF and $\pm46\%$ in VBF), the statistics of the simulated event samples ($\pm5\%$ in ggF and $\pm23\%$ VBF), as well as the flavour-tagging efficiency ($\pm5\%$ in ggF and $\pm6\%$ VBF). The cross section times branching ratios for the ggF and VBF production modes are found to be:

$$\sigma_{ggF}\times\mathscr{B}_{H\to WW^{*}}=12.6^{+1.3}_{-1.2}(stat.)^{+1.9}_{-1.8}(sys.)\,\mathrm{pb}$$

$$\sigma_{VBF}\times\mathscr{B}_{H\to WW^{*}}=0.5^{+0.24}_{-0.23}(stat.)\pm0.18(sys.)\,\mathrm{pb}\ .$$

The predicted values are 10.4 ± 0.6 pb (for ggF) and 0.81 ± 0.02 pb (for VBF), respectively. Hence the signal strength parameters, defined as the ratio of the measured to predicted production cross section, are $\mu_{ggF}=1.21^{+0.12}_{-0.11}(stat.)^{+0.18}_{-0.17}(syst.)$ and $\mu_{VBF}=0.62^{+0.30}_{-0.28}(stat.)\pm0.22(syst.)$. Thus the measurements are consistent with the SM prediction within one standard deviation. The observed (expected) significances are 6.3 (5.2) standard deviations for the ggF production mode and 1.9 (2.7) standard deviations for the VBF production mode. The two dimensional 68% and 95% CL contours of $\sigma_{ggF}\times\mathscr{B}_{H\to WW^{*}}$ and $\sigma_{VBF}\times\mathscr{B}_{H\to WW^{*}}$ are presented in Figure 2 together with the Standard Modell predictions.

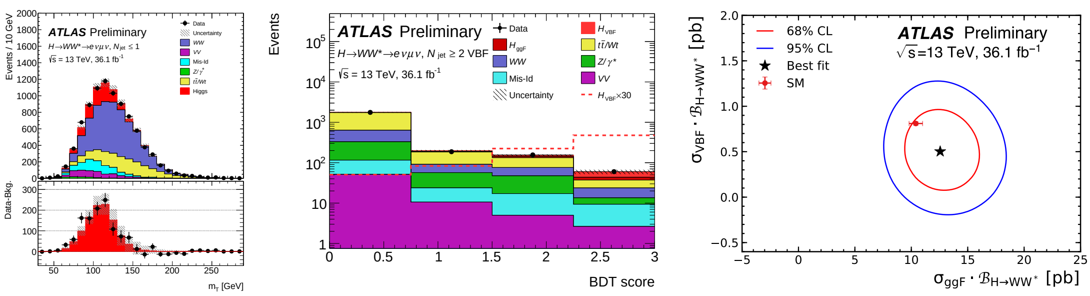

Figure 2: Post-fit distribution of the transverse mass for the ggF analyis (left) and the BDT response for the VBF analysis (middle), as well as the 68% and 95% confidence level two-dimensional likelihood contours of the $\sigma_{ggF}\times\mathscr{B}_{H\to WW^{*}}$ vs. $\sigma_{VBF}\times\mathscr{B}_{H\to WW^{*}}$ compared to the SM prediction (right) [2].

The latest measurements of the Higgs boson production cross section via associated WH production is based on a part of the 2015 and 2016 proton-proton collision runs of the LHC and corresponds to an integrated luminosity of $5.8\,\mathrm{fb}^{-1}$ recorded by the ATLAS detector at $\sqrt{s} = 13\,\mathrm{TeV}$.

For this measurement, candidate events with exactly three charged leptons are considered and further classified into two orthogonal categories according to the lepton pairing. One of these categories targets events with at least one same-flavour opposite charge pair and the other category contains events with no same-flavour opposite charge pair. The first region is dominated by processes containing Z-bosons, while the second one is Z-boson depleted. The normalisation of the most dominant backgrounds ($WZ/W\gamma^*$, $Z\gamma$, Z+jets and $t\bar{t}+V$) is obtained from data.

The cross section times branching ratio for the associated production of a Higgs boson and a W boson is determined via a simultaneous fit to all signal and control regions using simply the event rates in all considered categories. Systematic uncertainties enter as nuisance parameters in the likelihood function. The dominant uncertainties are related to the statistics of the data set ($\sim 120\%$) and the simulated event samples ($\sim 70\%$), pile-up activity ($\sim 24\%$), Jet energy resolution ($\sim 23\%$), the modelling of the most dominant background processes (e.g. $\sim 20\%$ on the modelling of the $t\bar{t}$) production. The production cross section times branching ratio was found to be

$$\sigma_{WH} \times \mathscr{B}_{H\to WW^*} = 0.9^{+1.1}_{-0.9}(stat.)^{+0.7}_{-0.8}(sys.)\,\mathrm{pb}\ ,$$

while the predicted production cross section is $0.293 \pm 0.007\,\mathrm{pb}$. Hence, the signal strength parameter is $\mu_{WH} = 3.2^{+3.7}_{-3.2}(stat.)^{+2.3}_{-2.7}(syst.)$. The observed (expected) significance is 0.77σ (0.24σ), thus an upper limit is set to the cross section times branching ratio of the WH production mode, which is found to be 3.3 pb at the 95% confidence level. The post-fit distribution of the event yields in the various signal and control regions are presented in Figure 3.

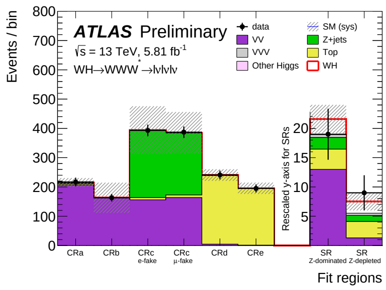

Figure 3: Fit regions used in the WH cross section measurement. The signal and background predictions are normalised to the results of the likelihood fit [3].

References

[1] ATLAS Collaboration, "The ATLAS Experiment at the CERN Large Hadron Collider", 2008 JINST 3 S08003.

[2] ATLAS Collaboration, "Measurements of gluon-gluon fusion and vector-boson fusion Higgs boson production cross-sections in the $H \to WW^* \to e\nu\mu\nu$ decay channel in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector", 2018, arXiv:1808.09054.

[3] ATLAS Collaboration, " Measurements of the Higgs boson production cross section via Vector Boson Fusion and associated WH production in the $WW^* \to \ell\nu\ell\nu$ decay mode with the ATLAS detector at $\sqrt{s} = 13\,\mathrm{TeV}$", ATLAS-CONF-2016-112, https://cds.cern.ch/record/2231811.