PROCEEDINGS OF SCIENCE

Cross-section measurements of the Higgs boson decaying to a pair of tau leptons in proton–proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector

Zinonas Zinonos[*†]
Max-Planck-Institut für Physik, München
E-mail: zenon@cern.ch

A measurement of total production cross sections of the Higgs boson in proton–proton collisions is presented in the $H \to \tau\tau$ decay channel. The analysis is performed using 36.1 fb^{-1} of data recorded by the ATLAS experiment at the Large Hadron Collider at a center-of-mass energy of $\sqrt{s} = 13$ TeV. Total cross sections are determined separately for vector boson fusion production and gluon-gluon fusion production. All measurements are in agreement with Standard Model expectations of a Higgs boson with mass of 125 GeV.

ICHEP 2018, 39th International Conference on High Energy Physics
4-11 July 2018
Seoul, Korea

[*] Speaker.
[†] On behalf of the ATLAS collaboration

PoS(ICHEP2018)104

1. Introduction

This proceedings presents cross-section measurements of Higgs bosons decaying into a pair of tau leptons in proton–proton (pp) collisions at $\sqrt{s} = 13$ TeV using data collected by the ATLAS experiment in 2015 and 2016, corresponding to an integrated luminosity of 36.1 fb^{-1}.

All combinations of leptonic ($\tau \to \ell\nu\bar{\nu}$ with $\ell = e, \mu$) and hadronic ($\tau \to$ hadrons ν) tau decays are considered: $\tau_{\rm lep}\tau_{\rm lep}$, $\tau_{\rm lep}\tau_{\rm had}$ and $\tau_{\rm had}\tau_{\rm had}$. These decay channels are composed of different dominant backgrounds. While $Z \to \tau\tau$ is a dominant background in all channels, the relative contributions from other backgrounds from top-quark and vector-boson decays, as well as from misidentified leptonic or hadronic tau decays, vary considerably.

Two analysis categories are defined that are predominantly sensitive to Higgs bosons produced via vector-boson fusion (VBF) and gluon-gluon fusion (ggH). A maximum likelihood fit is performed on data using distributions of the reconstructed di-tau mass in signal regions (SRs), simultaneously with event yields from control regions (CRs) that are included to constrain normalizations of major backgrounds estimated from simulation. The dominant and irreducible $Z \to \tau\tau$ background is estimated from simulation. A reliable modeling of this background is therefore of critical importance for this analysis and is checked in dedicated validation regions (VRs). The latter are based on $Z \to \ell\ell$ events are studied to verify as precisely as possible the modeling of the $Z \to \tau\tau$ background. However, these VRs are not included in the statistical fit. The modeling of the $Z \to \ell\ell$ background was found to be in a very good agreement with data.

2. Event Selection and Results

The data used in this analysis are taken from pp collisions at the LHC where proton bunches are collided every 25 ns. A combination of several triggers for single light leptons, two light leptons and two hadronically-decaying tau leptons are used to record the data for the analysis, depending on the analysis channel. In addition to data quality criteria which ensure that the detector was functioning properly, events are rejected if they contain reconstructed jets not associated to real energy deposits that can arise from hardware problems, beam conditions or cosmic showers. Depending on the trigger, transverse momentum requirements are applied to selected electron, muon, and hadronic tau candidates.

The Higgs boson candidate is reconstructed from the visible decay products of the tau leptons and from the missing transverse energy ($E_{\rm T}^{\rm miss}$) which is assumed to originate from the final state neutrinos. The di-tau invariant mass ($m_{\tau\tau}^{\rm MMC}$) is determined using the Missing Mass Calculator (MMC) [2].

Selected events are categorized into exclusive signal regions with enhanced signal-to-background ratios. In addition, control regions (CRs) are defined where a specific background is dominant and thereby allow the adjustment of simulated predictions for the background contribution to the observed data.

The final-state topologies of the three analysis channels have different background compositions which necessitates different strategies for the background estimation. In each SR, the number of expected background events and the associated kinematic distributions are derived from a mixture of data-driven methods and simulation.

To exploit signal-sensitive event topologies, a vector-boson fusion, 'VBF', and a 'boosted' analysis category are defined without any overlap in phase space.

The VBF category targets events with a Higgs boson produced by VBF and is characterized by the presence of a second high-p_{T} jet with $p_{\mathrm{T}} > 30$ GeV. In addition, the two jets are required to be in opposite hemispheres of the detector with a large pseudorapidity separation of $|\Delta\eta_{jj}| > 3$ and their invariant mass (m_{jj}) is required to be larger than 400 GeV. The selected leptons are required to have η-values that lie between those of the two jets. Although this category is dominated by VBF production, it also includes significant contributions from the ggH production, amounting to up to 30% of the total expected Higgs-boson signal.

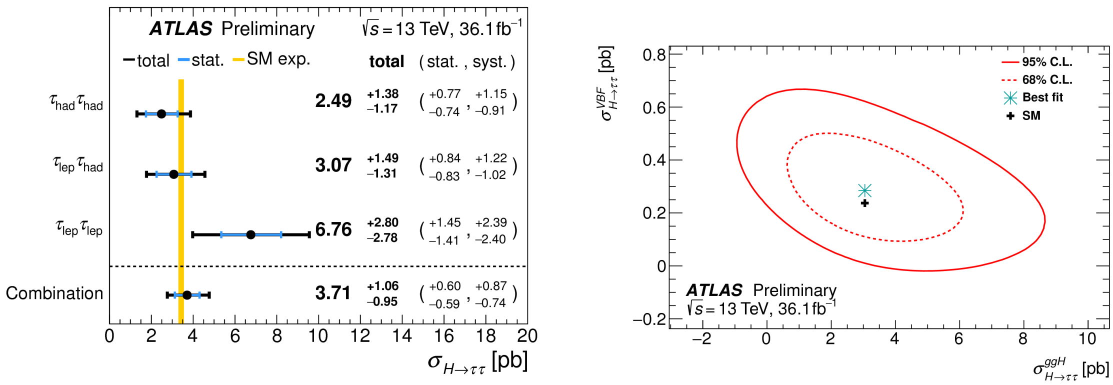
The boosted category targets events with Higgs bosons produced through ggH with an additional recoiling jet, which is motivated by an on average higher p_{T} of the boson for $H \to \tau\tau$ compared to the largest background from $Z \to \tau\tau$. It contains all events with $p_{\mathrm{T}}^{\tau\tau} > 100$ GeV that do not pass the VBF selection. In addition to events from ggH, the boosted categories contain sizeable contributions from VBF and VH production of 10-20% of the expected signal. Events that pass the event selection, but do not fall into the VBF or boosted categories are not used in the analysis.

Multiple control regions are defined to constrain in the fit the normalization of the dominant backgrounds in regions of phase space where their purity is high.

The expected signal and background yields in the various signal and control regions as well as the shape of the $m_{\tau\tau}^{\mathrm{MMC}}$ distributions in the signal regions are affected by systematic uncertainties. These are grouped into three categories: theoretical uncertainties in signal, theoretical uncertainties in background and experimental uncertainties, and included in the statistical model as nuisance parameters for the fit. The uncertainties in backgrounds from misidentified tau leptons, which are estimated using data-driven techniques, are also considered.

A maximum likelihood fit is performed on data to extract the parameter of interest defined as $\sigma_{H\to\tau\tau} \equiv \sigma_H \cdot \mathscr{B}(H \to \tau\tau)$ where σ_H is the total cross section of the considered Higgs boson production processes ggH, VBF and VH, and $\mathscr{B}(H \to \tau\tau)$ is the $H \to \tau\tau$ branching fraction. In this fit, the $m_{\tau\tau}^{\mathrm{MMC}}$ relative contributions from the various Higgs production processes are assumed as predicted by the Standard Model (SM). A probability model is constructed that describes the distributions in all signal regions and the event yields in adjacent control regions. The latter are included to constrain the normalizations of the dominant backgrounds.

Results of the fit when only the data of an individual channel or of an individual category are used are shown in Figure 1a. Also shown is the result from the combined fit and the uncertainty in $\sigma_{H\to\tau\tau}^{\mathrm{SM}}$. All results are consistent with the SM expectation. The simple combination of the individual fit results does not agree exactly with the combined fit result because the values of the nuisance parameters are different. This figure illustrates that both the VBF and boosted categories provide good sensitivity, respectively, to VBF and ggH Higgs boson production. A two-parameter fit is therefore performed to determine the cross sections of these production processes by exploiting the sensitivity offered by the use of the event categories in the analyses of the three channels. Two cross-section parameters are introduced and the data are fitted separating the fermion-mediated ggH process from the vector-boson-mediated VBF process while the contributions from other Higgs production processes are set to their predicted SM values. The two-dimensional 68% and 95% confidence level (CL) contours in the plane of the two cross-section parameters are shown Fig-



(a) Measured $\sigma_{H\to\tau\tau}$ per decay channel. (b) $\sigma^{\text{VBF}}_{H\to\tau\tau}$ versus $\sigma^{\text{ggH}}_{H\to\tau\tau}$ C.L. contours.

Figure 1: **Left**: The measured values for $\sigma_{H\to\tau\tau}$ when the data of individual channels are used. Also shown is the result from the combined fit. The total $\pm 1\sigma$ uncertainty in the measurement is indicated by the black error bars, with the individual contribution from the statistical uncertainty in blue. The theory uncertainty in the predicted signal cross section is shown by the yellow band. **Right**: Likelihood contours for the combination of all channels in the ($\sigma^{\text{ggH}}_{H\to\tau\tau}$, $\sigma^{\text{VBF}}_{H\to\tau\tau}$) plane. The 68% and 95% CL contours are shown as dashed and solid lines, respectively, for $m_H = 125$ GeV. The SM expectation is indicated by a plus symbol and the best fit to the data is shown as a star [1].

ure 1b. Total cross sections in the $H \to \tau\tau$ decay channel are measured separately for the VBF and ggH production to be $0.28 \pm 0.09(\text{stat.})^{+0.11}_{-0.09}(\text{syst.})$ pb and $3.0 \pm 1.0(\text{stat.})^{+1.6}_{-1.2}(\text{syst.})$ pb, respectively. All measurements are in agreement with SM expectations.

3. Conclusions

A measurement of total production cross sections of the Higgs boson in pp collisions is presented in the $H \to \tau\tau$ decay channel. The analysis is performed using LHC data recorded by the ATLAS experiment $\sqrt{s} = 13$ TeV in 2015-2016. All combinations of leptonic and hadronic tau decays are considered. The $H \to \tau\tau$ signal over the expected background from other SM processes is established with an observed (expected) significance of 4.4 (4.1) standard deviations. Combined with results using data taken at 7 and 8 TeV centre-of-mass energies, the observed (expected) significance amounts to 6.4 (5.4) standard deviations and constitutes an observation of $H \to \tau\tau$ decays by the ATLAS experiment. Using the data taken at $\sqrt{s} = 13$ TeV, the total cross section in this decay channel is measured and found to be consistent with the SM predictions assuming a mass for the Higgs boson of 125 GeV.

References

[1] ATLAS collaboration, "Cross-section measurements of the Higgs boson decaying to a pair of tau leptons in proton–proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector," ATLAS-CONF-2018-021, August 2018

[2] A. Elagin *et al.*, "A New Mass Reconstruction Technique for Resonances Decaying to di-tau," Nucl. Instrum. Meth. A **654**, 481 (2011) doi:10.1016/j.nima.2011.07.009, arXiv:1012.4686