IL NUOVO CIMENTO **43 C** (2020) 86
DOI 10.1393/ncc/i2020-20086-3

Colloquia: IFAE 2019

# Measurements of the Higgs production cross section in the $H \to \tau\tau$ decay channel with the ATLAS experiment

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received 8 June 2020

**Summary.** — Measurements of the Higgs production cross section in the $H \to \tau\tau$ decay channel are presented. The analysis has been performed using 36.1 fb$^{-1}$ of data collected by the ATLAS experiment at $\sqrt{s} = 13$ TeV proton-proton collisions at the Large Hadron Collider. The observed (expected) significance of the $H \to \tau\tau$ signal excess over the expected background amounts to 4.4 (4.1) standard deviations. This result, combined with the data taken at $\sqrt{s} = 7$ and 8 TeV, leads to an observed (expected) significance of 6.4 (5.4) standard deviations and constitutes the first ATLAS observation of $H \to \tau\tau$. All the reported measurements are in agreement with the Standard Model predictions.

## 1. – Introduction

In 2012 the ATLAS and CMS experiments discovered a particle consistent with the Standard Model (SM) Higgs boson [1, 2]. After the Higgs boson discovery, the studies have been focused on measuring its properties such as coupling strengths, spin and CP quantum numbers. Several measurements have been performed during Run 1 of the LHC at a center-of-mass energy of $\sqrt{s} = 7$ and 8 TeV and they have not shown any deviation from the SM expectations. Among Higgs couplings to fermions, only the ones to third generation fermions are currently accessible at the LHC. The $H \to \tau\tau$ decay channel is of considerable importance since it allows the Higgs-Yukawa coupling to leptons to be directly measured(1). The observation of the $H \to \tau\tau$ decay has already been established by the ATLAS and CMS combined measurement using Run 1 data, with a significance of $5.5\sigma$ [3]. Nevertheless the $H \to \tau\tau$ channel can benefit from the higher Run 2 statistics in order to reach larger precision results.

The analysis [4] presented in this paper has been performed using the 2015 and 2016 data recorded by the ATLAS detector [5] at the LHC, corresponding to an integrated

(1) Limits have been set to the $H \to \mu\mu$ but there is not an evidence yet.

luminosity of $36.1\,\text{fb}^{-1}$. All combinations of possible decay modes have been exploited in the analysis: both leptonic ($\tau \to l\nu\bar{\nu}$ with $l = e, \mu$) and hadronic ($\tau \to$ hadrons $\nu$) $\tau$ decays. The three decay channels will henceforth be referred to as $\tau_{\text{lep}}\tau_{\text{lep}}$, $\tau_{\text{lep}}\tau_{\text{had}}$ and $\tau_{\text{had}}\tau_{\text{had}}$.

## 2. – Analysis strategy

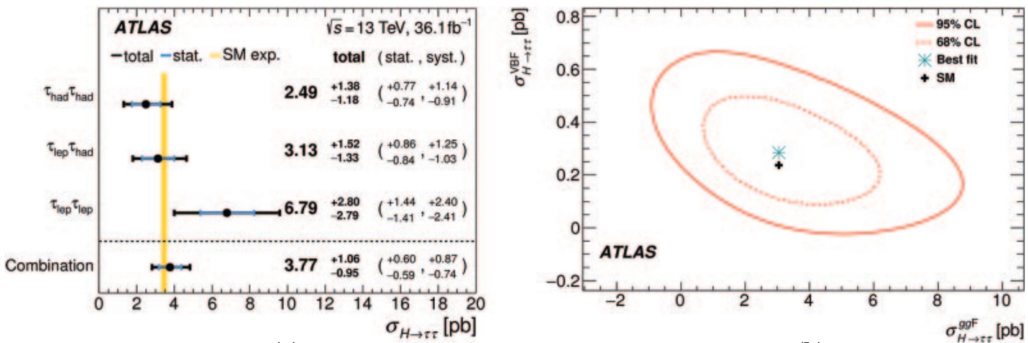
The analysis aims at measuring the Higgs boson production cross section exploiting signal-sensitive event topologies. Therefore, two kinds of signal regions (SRs) are defined: one region called "VBF", which targets events produced through vector boson fusion (VBF), and a region called "boosted", which targets events produced through gluon-gluon fusion (ggF) with an additional recoiling jet. These two kinds of SRs are obtained by applying some kinematic requirements. The VBF is characterized by two high-$p_{\text{T}}$ jets, which are required to have a large pseudorapidity separation ($|\Delta\eta_{jj}| > 3$) and large invariant mass ($m_{jj} > 400\,\text{GeV}$). The boosted category contains instead events that fail the VBF selection and are characterized by a high-$p_{\text{T}}$ Higgs boson ($p_{\text{T}}^{H} > 100$ GeV). The Higgs invariant mass reconstructed with the Missing Mass Calculator (MMC) [6] algorithm, is the variable used in the SRs.

The different final states of the three decay channels imply different background compositions and also need different strategies for background estimation. The Drell-Yan process $Z/\gamma^* \to \tau\tau$ constitutes the main irreducible background. This is estimated using Monte Carlo generators. The normalization is retrieved from the fit to data and no specific control region (CR) is defined. Therefore, a validation region (VR) containing $Z \to ll$ events is used instead to verify the correct modelling of the $Z \to \tau\tau$ process. Another significant background arises from hadronic jets which are misidentified as $\tau_{\text{had}}$ or as electrons or muons. The main sources of this background come from QCD jets and $W/Z$ bosons produced in association with jets. The misidentified $\tau$ background is estimated using three different data-driven techniques according to the specific decay channel. Dedicated CRs are defined for other relevant backgrounds, *i.e.*, the $Z \to ll$ process in the case of the $\tau_{\text{lep}}\tau_{\text{lep}}$ channel and the top-quark background, significant for both the $\tau_{\text{lep}}\tau_{\text{lep}}$ and the $\tau_{\text{lep}}\tau_{\text{had}}$ channel.

A maximum likelihood fit is performed on data in order to extract the parameter of interest, namely the $\sigma_{H\to\tau\tau}$ total cross section. A fit model is constructed using the $m_{\tau\tau}^{\text{MMC}}$ distributions in the SRs and only the event yields in the CRs. SRs are modeled by a product of Poisson distributions, each of this distribution representing the event yield in intervals of $m_{\tau\tau}^{\text{MMC}}$ while CRs are modeled by a single Poisson distribution that describes the event count in that region. Systematic uncertainties are also taken into account as nuisance parameters and parametrized by Gaussian or log-normal distributions. Significant contributions to systematic uncertainties arise from signal theory uncertainties and jet energy-related uncertainties.

## 3. – Results

The measured value of $\sigma_{H\to\tau\tau}$ is $3.77^{+0.60}_{-0.59}$ (stat.) $^{+0.87}_{-0.74}$ (syst.) pb where all the relative contributions of the Higgs production processes are assumed to be as predicted by the SM. This value is compatible with the SM prediction, which is $\sigma^{\text{SM}}_{H\to\tau\tau} = 3.46 \pm 0.13\,\text{pb}$, as shown in fig. 1(a). In addition, since the VBF and boosted categories are sensitive to the VBF and ggF production mechanism respectively, a two-parameters fit




**(a)** **(b)**

Fig. 1. – (a) $\sigma_{H\to\tau\tau}$ measurement in the various subchannels and for the combined result, with the SM prediction and its uncertainty shown in yellow, and (b) 95% and 68% C.L. contours in the plane of $\sigma^{VBF}_{H\to\tau\tau}$, $\sigma^{ggF}_{H\to\tau\tau}$ with the SM value indicated by the black point and the best-fit value shown as a star [4].

has also been performed to determine the cross sections of these production processes. The resulted values are $\sigma^{\mathrm{VBF}}_{H\to\tau\tau} = 0.28 \pm 0.09$ (stat.) ${}^{+0.11}_{-0.09}$ (syst.) pb and $\sigma^{gg\mathrm{F}}_{H\to\tau\tau} = 3.1 \pm 1.0$ (stat.) ${}^{+1.6}_{-1.3}$ (syst.) pb. Both cross sections values are in agreement with the SM predictions (fig. 1(b)).

The observed (expected) significance of the signal excess relative to the background-only hypothesis is 4.4 (4.1) $\sigma$. This result, combined with the Run 1 result [7] obtained using data collected at 7 and 8 TeV center-of-mass energies, leads to an observed (expected) significance of 6.4 (5.4) $\sigma$. This constitutes the first ATLAS observation of the $H \to \tau\tau$ decay.

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