PROCEEDINGS OF SCIENCE

Search for the Standard Model Higgs boson in the $H \to \tau^+\tau^-$ decay mode with the ATLAS detector

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A search for the Standard Model Higgs boson decaying into a pair of τ leptons is reported. The analysis is based on a data sample of proton-proton collisions collected by the ATLAS experiment at the LHC and corresponding to an integrated luminosity of 4.7 fb^{-1}. No significant excess over the expected background is observed in the Higgs boson mass range of 100–150 GeV. The observed (expected) upper limits on the cross section times the branching ratio for $H \to \tau^+\tau^-$ are found to be between 2.9 (3.4) and 11.7 (8.2) times the Standard Model prediction for this mass range.

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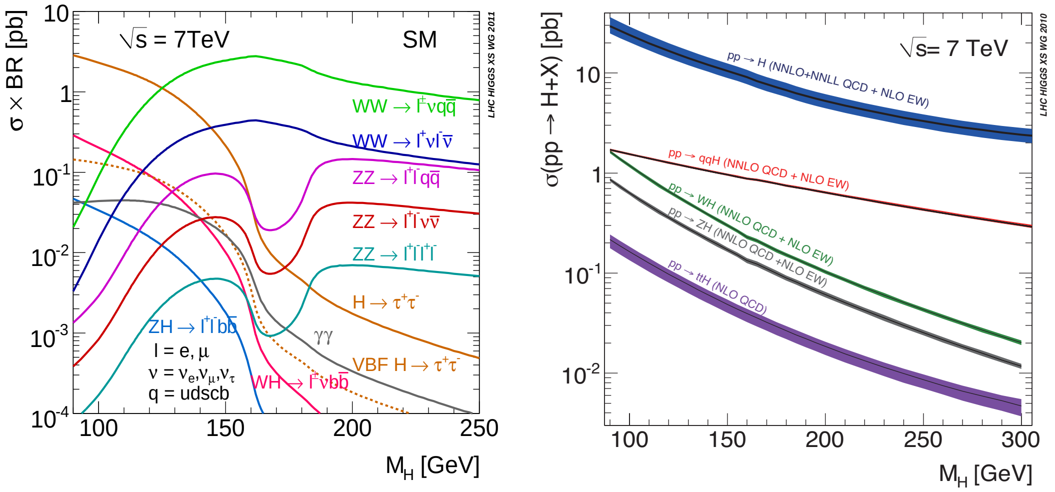
1. Introduction

The decay of a Standard Model (SM) Higgs boson (H) into a pair of τ leptons provides direct probe into the Yukawa coupling of fermions, which gives mass to all the quarks and leptons. In the region of interest around 125 GeV [1] , $H \to \tau^+\tau^-$ has one of the largest branching ratios [2], as shown in Fig. 1. In order of decreasing cross-sections, three mechanisms contribute to Higgs production: gluon-gluon fusion (ggF), vector-boson fusion (VBF) and associated vector boson (VH) production [2]. However, the experimental signature is cleaner for VBF (VH) processes, due to the presence of two additional jets in the opposite (same) hemisphere.



(a) Cross-section times branching ratio (b) Production modes

Figure 1: Cross-section times branching ratio (left) and different components of production cross-section (right) of a SM Higgs boson produced in pp collisions at $\sqrt{s} = 7$ TeV [2].

2. Analysis

In terms of the τ decay products, the search for SM $H \to \tau^+\tau^-$ decays using data collected in pp collisions at $\sqrt{s} = 7$ TeV by the ATLAS experiment [3] is split into 3 channels: $H \to \tau_{\rm had}\tau_{\rm had}$, $H \to \tau_{\rm lep}\tau_{\rm had}$ and $H \to \tau_{\rm lep}\tau_{\rm lep}$. In the $H \to \tau_{\rm had}\tau_{\rm had}$ channel, there is only a 1-jet category. In the $H \to \tau_{\rm lep}\tau_{\rm had}$ channel, there are seven categories: electron and muon flavors separately for both 0- and 1-jet categories, and electron and muon flavors combined in the 2-jet VBF category. The 0-jet category is further split into low and high regions depending upon whether the missing transverse energy $(E_T^{\rm miss})$ is less than or greater than 20 GeV. In the $H \to \tau_{\rm lep}\tau_{\rm lep}$ channel, there are four categories: 0-jet, 1-jet, 2-jet VBF and 2-jet VH. Thus, a total of 12 categories are considered in the analysis. The 0-jet category in $H \to \tau_{\rm lep}\tau_{\rm lep}$ channel uses effective mass defined as $m_{\tau\tau}^{eff} = (p_{\ell^+} + p_{\ell^-} + E_T^{\rm miss})^2$. In all other categories in $H \to \tau_{\rm lep}\tau_{\rm lep}$ and $H \to \tau_{\rm had}\tau_{\rm had}$ channels, the collinear di-tau mass reconstruction [4] is used. For all categories in $H \to \tau_{\rm lep}\tau_{\rm had}$ channel, di-tau mass reconstructed with missing mass constraint (MMC) [5] is used. These distributions for the $H \to \tau_{\rm had}\tau_{\rm had}$, $H \to \tau_{\rm lep}\tau_{\rm had}$ and $H \to \tau_{\rm lep}\tau_{\rm lep}$ channels are shown in Figs. 2, 3, and 4, respectively.

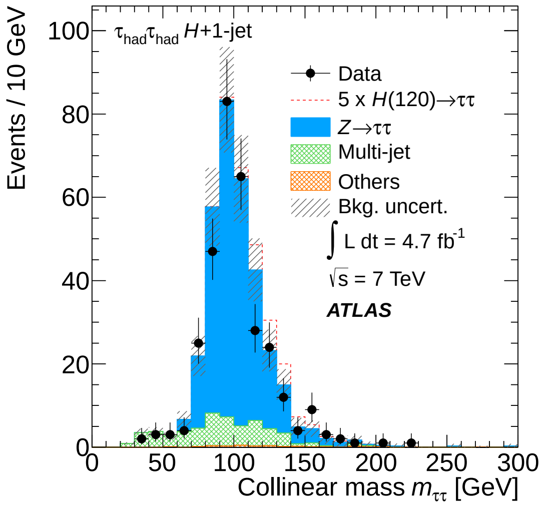


Figure 2: Reconstructed $m_{\tau\tau}$ of the selected events in the $H \to \tau_{\rm had}\tau_{\rm had}$ channel. Expectations from the Higgs boson signal ($m_H = 120$ GeV) and from backgrounds are given. For illustration only, the signal contribution has been scaled by a factor given in the legend.

In terms of the parameter of interest, the signal strength μ defined as the ratio of the measured cross-section normalized to the Standard Model cross-section times the branching ratio for $H \to \tau^+\tau^-$ decays, a binned likelihood function $\mathscr{L}(\mu,\theta)$ is defined from the number of events (N_j) in each bin of the $\tau\tau$ mass distributions per category per channel as:

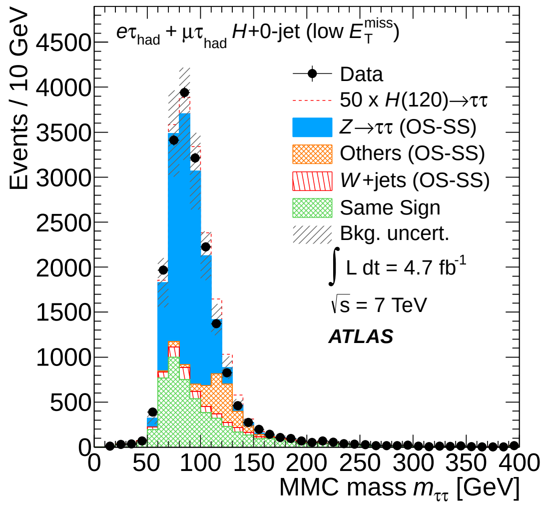
$$\mathscr{L}(\mu,\theta) = \prod_{\rm channel}\prod_{\rm category}\left[\prod_{{\rm bin}\,j}{\rm Poisson}(N_j|\mu\cdot s_j + b_j)\prod_{\theta}{\rm Gaussian}(t|\theta,1)\right]. \tag{2.1}$$

The value $\mu = 0$ ($\mu = 1$) corresponds to the absence (presence) of a Higgs boson signal with the SM production cross-section. Signal and background predictions (s_j and b_j) are parametrized by nuisance parameters θ describing systematic uncertainties, which are constrained by auxiliary measurements t of various scale factors and dedicated calibration constants obtained from control regions in the data.

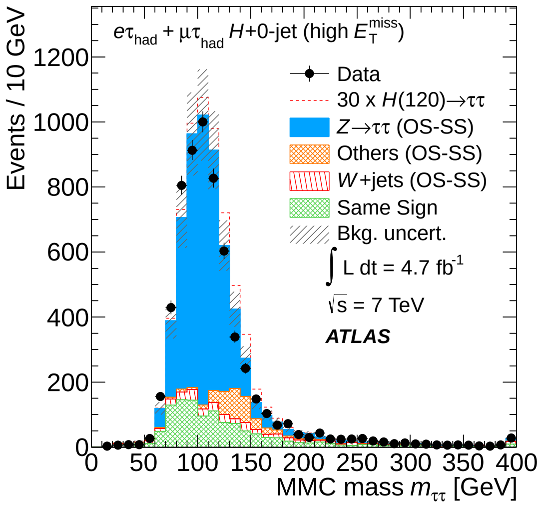
Following the modified frequentist CL_s method [6], the compatibility with respect to the signal hypothesis is tested using asymptotic approximations [7]. The results are presented in Fig. 5.

3. Results and Summary

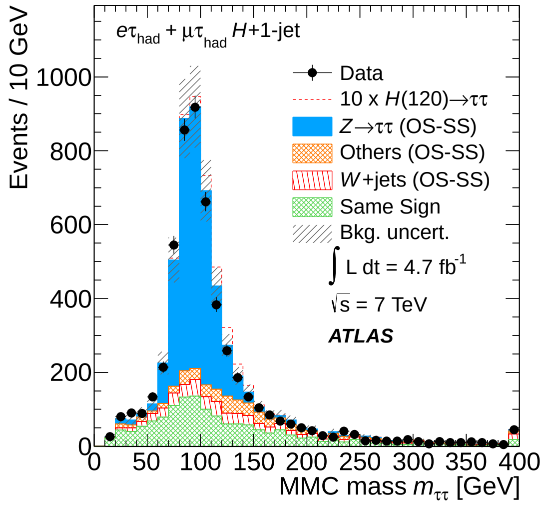
A search for a Higgs boson decaying in the $H \to \tau\tau$ channel has been performed with the ATLAS detector [3]. It uses the full 2011 data sample of $4.7\,{\rm fb}^{-1}$ collected at a centre-of-mass energy of 7 TeV. The $H \to \tau_{\rm had}\tau_{\rm had}$, $H \to \tau_{\rm lep}\tau_{\rm had}$ and $H \to \tau_{\rm lep}\tau_{\rm lep}$ decays are considered in this search. No significant excess is observed in the mass range of 100–150 GeV. The observed (expected) upper limits on the cross section times the branching ratio of $H \to \tau\tau$ are between 2.9 (3.4) and 11.7 (8.2) times the SM prediction. These limits are similar to results recently reported by the CMS experiment [8].



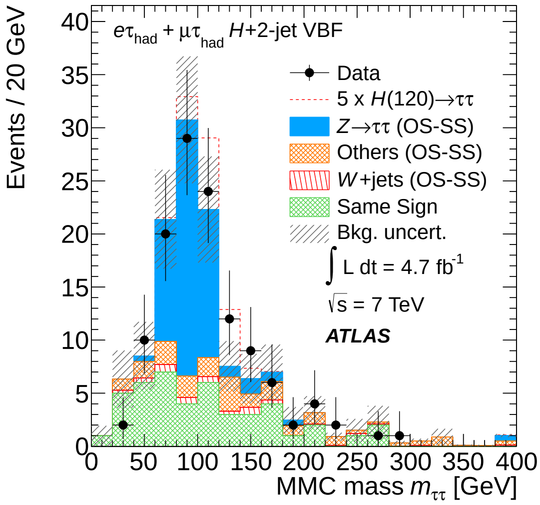
(a) Combined $H+$0-jet (low E_T^{miss})



(b) Combined $H+$0-jet (high E_T^{miss})

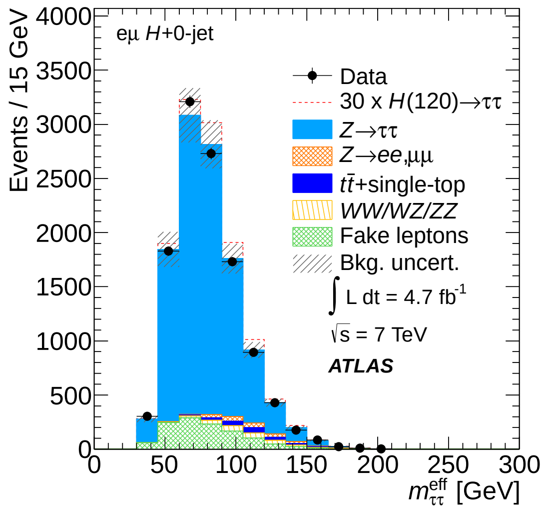


(c) Combined $H+$1-jet

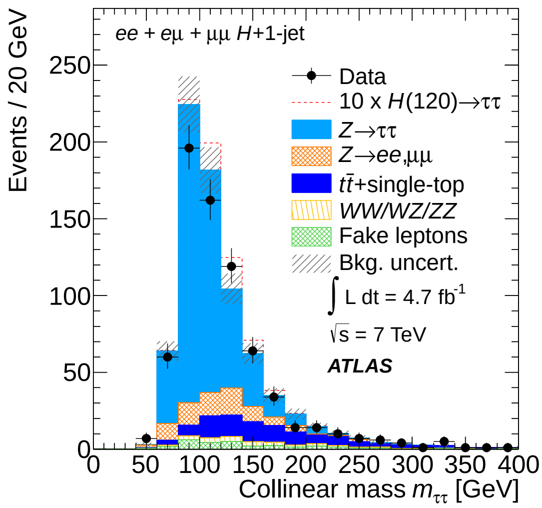


(d) $H+$2-jet VBF

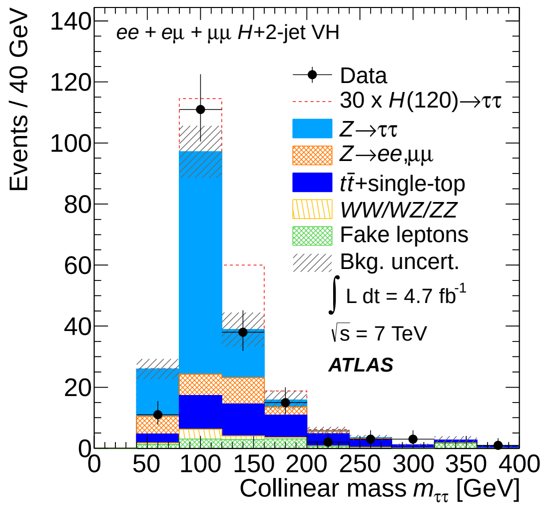
Figure 3: MMC mass distributions of the selected events in the $H \to \tau_{\mathrm{lep}}\tau_{\mathrm{had}}$ channel. The corresponding electron and muon categories for the $H+$0-jet and $H+$1-jet categories are shown combined here, while in the data analysis they are considered separately. The selected events in data are shown together with the predicted Higgs boson signal ($m_H = 120$ GeV) stacked above the background contributions. For illustration only, the signal contributions have been scaled by factors given in the legends.



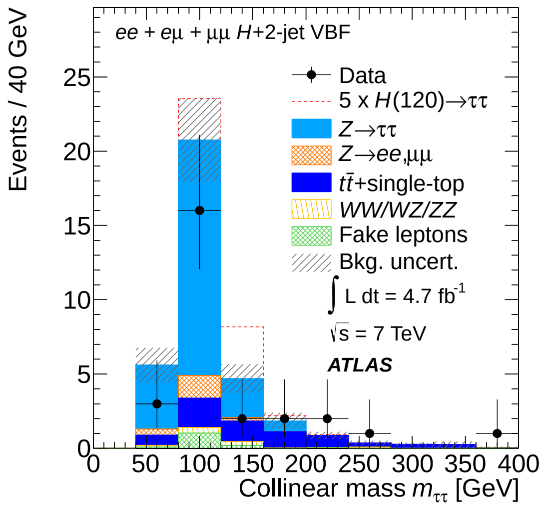
(a) $H+0$-jet



(b) $H+1$-jet

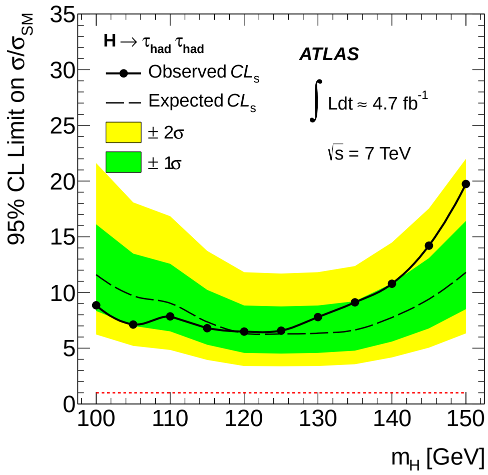


(c) $H+2$-jet VH

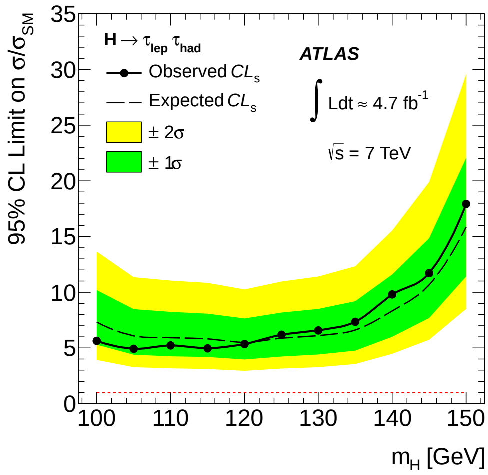


(d) $H+2$-jet VBF

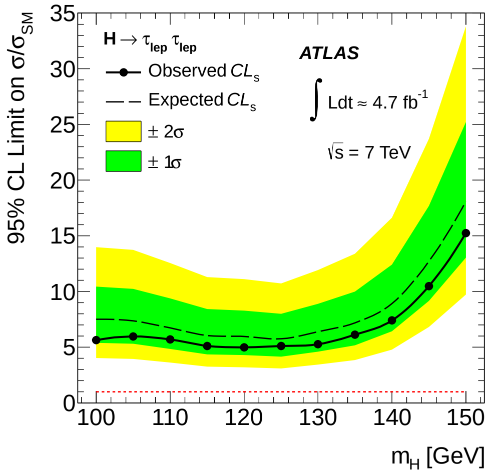
Figure 4: Reconstructed $m_{\tau\tau}$ of the selected events in the $H \to \tau_{\text{lep}}\tau_{\text{lep}}$ channel for the categories as described in the text. Simulated samples are normalized to an integrated luminosity of $4.7\,\text{fb}^{-1}$. Predictions from the Higgs boson signal ($m_H = 120$ GeV) and from backgrounds are given. In the case of the $H+0$-jet category $m_{\tau\tau}^{\text{eff}}$ is used. For illustration only, the signal contributions have been scaled by factors given in the legends.



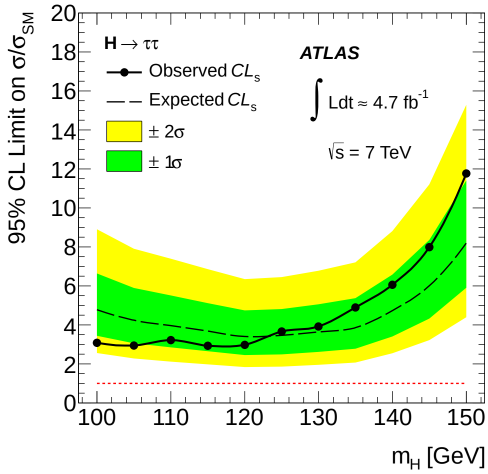
(a) $H \to \tau_{\rm had}\tau_{\rm had}$



(b) $H \to \tau_{\rm lep}\tau_{\rm had}$



(c) $H \to \tau_{\rm lep}\tau_{\rm lep}$



(d) Combined

Figure 5: Observed (solid) and expected (dashed) 95% confidence level upper limits for the $H \to \tau_{\rm lep}\tau_{\rm lep}$, $H \to \tau_{\rm lep}\tau_{\rm had}$, and $H \to \tau_{\rm had}\tau_{\rm had}$ channels independently and for all channels combined.

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