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Search for the standard model Higgs boson decaying to a pair of taus at CMS

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Abstract

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Abstract. A search for the standard model Higgs boson decaying to τ pairs is performed using events recorded by the CMS experiment at the LHC in 2011 and 2012. The dataset corresponds to an integrated luminosity of $4.9(19.4) \text{ fb}^{-1}$ at a centre-of-mass energy of $7(8) \text{ TeV}$. An excess of events is observed over a broad range of Higgs mass hypotheses, with a maximum local significance of 2.93 standard deviations at $m_H = 120 \text{ GeV}$. The excess is compatible with the presence of a standard model Higgs boson of mass 125 GeV .

1 Introduction

The discovery of a new boson, with mass around 125 GeV and with properties compatible with those of a standard model (SM) Higgs boson, H , was announced at CERN by the ATLAS and CMS collaborations [1,2] in July 2012. At both experiments, the observed excess is driven by the $H \rightarrow \gamma\gamma$, $H \rightarrow ZZ$ and $H \rightarrow WW$ decay modes. However it is critical to measure this new resonance in its decays to tau pairs, to determine if it is consistent with the SM Higgs boson or not. This search has been done by CMS experiment using full 2011 and 2012 data [3,4].

2 Event selection and exclusive categories

Full description of the CMS detector can be found in [5]. All particles are reconstructed using the particle flow (PF) algorithm [6], which focuses on using an optimized combination of subdetector information to reconstruct each individual particle with the highest accuracy. Five independent τ -pair final states are studied: $\mu\tau_h$, $e\tau_h$, $e\mu$, $\tau_h\tau_h$, and $\mu\mu$, where τ_h denotes a reconstructed hadronic τ decay. These final states are split into mutually exclusive categories based on the jet multiplicity, and on the transverse momentum of the reconstructed τ -decay products. Sensitivity to the associated production with a W or a Z boson is achieved by requiring one or two additional electrons or muons compatible with the leptonic decays of the W or Z boson. These categories are:

- **VBF:** In this category in order to tag the vector-boson fusion Higgs-production process, two jets with $p_T > 30 \text{ GeV}$ with invariant mass $M_{jj} > 500 \text{ GeV}$ and separated in pseudorapidity by $\Delta\eta > 3.5$ are required. Additionally, a rapidity gap is defined by requiring no additional jet with $p_T > 30 \text{ GeV}$ between the two tagging jets.

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- **1-jet:** Events in this category are required to have at least one jet with $p_T > 30$ GeV, not to be part of the VBF event category.
- **0-jet:** This category contains all events with no jet with $p_T > 30$ GeV and no b-tagged jet with $p_T > 20$ GeV. The 0-jet category is only used to constrain background normalization, identification efficiencies, and energy scales.
- **VH:** This event category is intended to exploit the production of Higgs bosons in association with a W or Z boson decaying to 1 or two leptons, respectively. In WH channels, W decays to muon or electron in the semi-leptonic or fully hadronic decay of the H boson (i.e. $\mu\tau_h$, $e\tau_h$ or $\tau_h\tau_h$). $ee\tau_h$ is not included. In the ZH channels, Z boson decays to a pair of electrons or muons and H boson decays to any of the four final states: $\mu\tau_h$, $e\tau_h$, $e\mu$ or $\tau_h\tau_h$.

The 0- and 1-jet categories are each further divided into two subsets, using the p_T of the visible τ -decay products, either hadronic or leptonic. In the $\tau_h\tau_h$ channel, a leading jet with $p_T > 50$ GeV and $|\eta| < 3.0$ is required to match the trigger requirement, and two categories, VBF and 1-jet are considered. In all categories, the large $t\bar{t}$ background contribution is suppressed by rejecting events containing a b-tagged jet of $p_T > 20$ GeV.

3 Background estimation

The estimation of the shape and yield of the major backgrounds in each channel is based on the observed data.

The largest source of background in non-VH channels is the Drell–Yan production of $Z \rightarrow \tau\tau$. This contribution is greatly reduced by the 1-jet and VBF selection criteria, and is modeled using “embedded” event samples from data using $Z \rightarrow \mu\mu$ selection. Apart from the decay products of the two τ leptons, the contents of the embedded events, and in particular the jets and the E_T^{miss} entirely come from data. The background yield is rescaled to the observed $Z \rightarrow \mu\mu$ yield before any jet selection. The background from $W + \text{jets}$ production, mainly contributing to the $e\tau_h$ and $\mu\tau_h$ channels, is normalized to the yield observed in a high- m_T control region dominated by the background and the factor for extrapolating to the low- m_T signal region is obtained from the simulation. QCD multijet events constitute another important source of background in the $e\tau_h$, $\mu\tau_h$ and $\tau_h\tau_h$ channels and is estimated entirely based on observed data using a control sample where both leptons are required to have the same charge. The expected background in the opposite-charge signal sample is then derived by rescaling the yield obtained in the same-charge control sample by a factor of 1.06, which is measured using a pure QCD multijet sample obtained by inverting the lepton isolation and relaxing the τ_h isolation.

Figure 1: Combined observed and expected $m_{\tau\tau}$ distributions for the $\mu\tau_h$, $e\tau_h$, $e\mu$ and $\tau_h\tau_h$ channels. The distributions obtained in each category of each channel are weighted by the ratio between the expected signal and background yields in the category.

For VH channels, the irreducible diboson backgrounds are WZ and ZZ events in the WH channels, and ZZ events in the ZH channels, and they are estimated using simulation. The reducible backgrounds have at least one fake lepton in the final state due to a misidentified quark or gluon jet which passes the lepton identification and are estimated solely using data. In the method called “fake rate”, the misidentification probabilities as a function of candidate p_T , for the fake lepton candidates to pass the final identification and isolation criteria are measured in independent, highly pure control regions and applied to sideband regions where the final identification or isolation criterion is not satisfied for one or more of the final-state lepton candidates.

The main source of systematics are estimation of background, tau identification efficiency and energy scale as well as theoretical uncertainty on the signal. Full set of systematic uncertainties can be found in [3, 4].

4 Results

Figure 1 shows the combined observed and expected $m_{\tau\tau}$ distributions, weighting all distributions in each category of each channel by the ratio between the expected signal and background yields for the category in a $m_{\tau\tau}$ interval containing 68% of the signal. It also shows the difference between the observed data and expected background distributions, together with the expected distribution for a SM Higgs boson signal with $m_H = 125$ GeV.

A statistical procedure based on a profile-likelihood ratio test statistic is used to search for the presence of a SM Higgs boson signal. The $m_{\tau\tau}$ distributions obtained for each category of the five channels at 7 TeV and 8 TeV

Figure 2: Observed and expected limit in the background hypothesis(left) and observed and expected significance(right)

are combined in a binned likelihood, involving for each bin the expected number of background events and the expected number of signal events, scaled by a signal strength parameter μ . In the dimuon channel, the binned likelihood includes the two-dimensional distribution of $m_{\tau\tau}$ versus the dimuon invariant mass $m_{\mu\mu}$. For VH channels, visible invariant mass spectrum of the Higgs boson candidates have been used. The systematic uncertainties are represented by nuisance parameters. The observed distribution is compared with the background prediction, which results from a global maximum-likelihood fit varying μ and all nuisance parameters. The best-fit value for the signal strength combining all channels is $\hat{\mu} = 1.1 \pm 0.4$ at $m_H = 125$ GeV.

Figure 2 (left) shows the observed 95% CL upper limit obtained using the modified frequentist construction CL_s together with the expected limit obtained in the background hypothesis. An excess is visible in the observed limit with respect to the limit expected for the background hypothesis. This excess is quantified in Figure 2 (right), which shows the p-value $1-\text{CL}_b$ for Higgs-boson mass hypotheses ranging from 110 to 145 GeV. The minimum p-value is observed at $m_H = 120$ GeV, corresponding to a significance of 2.93 standard deviations. For $m_H = 125.8$ GeV, the significance is 2.85σ .

References

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