PROCEEDINGS OF SCIENCE

Search for a Standard Model Higgs Boson Decaying to τ Pairs at CMS

Joshua Swanson*
On behalf of the CMS Collaboration
University of Wisconsin Madison
E-mail: swanson@hep.wisc.edu

A search for a Standard Model Higgs Boson decaying to tau pairs is done using data collected by the CMS detector at the LHC in 2011 and 2012. The dataset corresponds to 4.9 fb^{-1} and 5.1 fb^{-1} of data at 7 TeV and 8 TeV center-of-mass energy respectively. No significant excess of events is observed in the tau pair invariant mass spectrum. In the mass range of 110–145 GeV upper limits at 95% confidence level on the production cross section are determined. We exclude a Higgs boson with $m_H = 125$ GeV with a production cross section 1.06 times that predicted by the standard model at 95% confidence level.

36th International Conference on High Energy Physics
4-11 July 2012
Melbourne, Australia

*Speaker.

© Copyright owned by the author(s) under the terms of the Creative Commons Attribution-NonCommercial-ShareAlike Licence. http://pos.sissa.it/

PoS(ICHEP2012)067

1. Introduction

One of the defining goals of the LHC physics program was to discover the mechanism of electroweak symmetry breaking, which in turn explains the mass of the W and Z bosons when compared to the massless photon. In the standard model (SM) this is done via the Higgs Mechanism, which predicts an additional boson.

Previous searches have restricted the mass range available to the SM Higgs Boson to be less than 127 GeV [1]. In this mass range searches involving tau leptons (tau) become very important. Theory predicts that the branching ratio of Higgs decays to tau pairs in this mass range is on the order of 7%, which is much higher than what is available to the most common search channels of ZZ and $\gamma\gamma$. Additionally searches with tau pairs offer a probe of direct coupling to the fermions and is also sensitive to all Higgs production channels: gluon-gluon fusion, production in association with a W or Z boson (VH), and vector boson fusion (VBF).

This search is done using data collected with the Compact Muon Solenoid (CMS) experiment [3] at the Large Hadron Collider (LHC). The data sample includes a total of 10 fb^{-1} of integrated luminosity, 4.9 fb^{-1} of data collected at 7 TeV center-of-mass energy, 5.1 fb^{-1} of data collected at 8 TeV center-of-mass energy. Four different search modes are considered depending on which way the tau pairs decay: $\tau_\mu - \tau_h$, $\tau_e - \tau_h$, $\tau_e - \tau_\mu$, or $\tau_\mu - \tau_\mu$ where τ_μ, τ_e represent a tau that subsequently decays to a muon or electron and τ_h to the reconstructed hadrons from a hadronically decaying tau.

The final search strategy is defined in a way to emphasize events coming from different Higgs production modes. The largest Higgs production cross section at the LHC comes from gluon-gluon fusion events. This production is traditionally challenging due to large irreducible Drell-Yan to tau-tau background. To maximize the significance in this production mode we split first by the number of additional jets in the event into zero jet and one jet categories to take advantage of boosted Higgs topology where the Higgs candidate recoils off a jet coming from an initial state gluon. In addition to the splitting by jet the 0 and 1 jet categories the events are additionally split into high and low transverse momentum (p_T) categories to take advantage of the fact that leptons coming from the Higgs are harder. Lastly to exploit the VBF production topology we have a VBF category requiring two jets with a large rapidity separation.

2. Event Selection

Events are selected in the four decay channels first using the CMS [3] high level trigger system. A combination of electron, muon, and tau trigger objects are combined into distinct cross object triggers. These triggers and there evolution with increasing instantaneous luminosity and pile-up drive the p_T acceptance used in the analysis, a summary of the p_T and η acceptance used in this analysis can be found in table 1.

A particle flow algorithm is used to reconstruct the complete event. Namely information from all sub-detectors is combined together in order to identify individual particles: muons, electrons, photon, charged and neutral hadrons. Using the subsequent list of particles we reconstruct composite objects such as jets, hadronic taus, and missing transverse energy (E_T^{miss}). Hadronic taus are reconstructed using the hadron plus strips algorithm (HPS) [4]. The HPS algorithm identifies

PoS(ICHEP2012)067

Channel	Lepton	2011 p_T (GeV)	2012 p_T (GeV)	$\lvert\eta\rvert$
$\tau_\mu - \tau_h$	μ	17	20	2.1
$\tau_\mu - \tau_h$	τ_h	20	20	2.3
$\tau_e - \tau_h$	μ	20	20	2.1
$\tau_e - \tau_h$	τ_h	24	20	2.3
$\tau_e - \tau_\mu$	μ	20(10)	20(10)	2.1
$\tau_e - \tau_\mu$	e	10(20)	10(20)	2.3
$\tau_\mu - \tau_\mu$	μ	20(10)	20(10)	2.1

Table 1: Transverse momentum and psuedorapidity acceptance by channel and year.

τ_h candidates by combining charged hadrons and electromagnetic clusters in an attempt to reconstruct their decays. The τ_h identification in CMS provides efficiencies > 60% for real tau leptons compared to a jet fake rate of less than 3%. In addition to the object reconstruction particle flow information is used to isolate the reconstructed objects from QCD multi-jet events, radiated jets, and or jets from event pile-up.

2.1 Categories

The selected events are then split into 5 categories. First the events are split by the number of additional jets in the event, required to have $p_T > 30$ GeV and $|\eta| < 5.0$. There are zero jet, one jet, and VBF categories. The zero and one jet categories are then further split into high and low p_T categories. The high p_T categories are defined by the τ_h $p_T > 40$ GeV for $\tau_\mu - \tau_h$ and $\tau_e - \tau_h$ channels and the leading muon $p_T > 35$ (20) GeV in the $\tau_e - \tau_\mu$ ($\tau_\mu - \tau_\mu$) channel. The events not passing the high p_T requirements are selected by the low p_T categories. Finally there is a VBF category. VBF events are selected by requiring 2 or more jets then further categorized by a multivariate BDT discriminator, based on the invariant mass of the two jets, the differences $\Delta\eta_{jj}(\Delta\phi_{jj})$ in $\eta(\phi)$ between the two jets, the p_T of the $di-\tau$ system including missing transverse energy, the p_T of the di-jet system, the difference in η between the visible part of the $di-\tau$ system and the closest jet and the visible p_T of the $di-\tau$ system. Events with two or more jets that don't pass the VBF category requirements are put in the one jet categories.

3. Mass Reconstruction

Full mass information of the Higgs candidate is lost due to neutrinos produced in the decay of the tau leptons. An attempt to estimate the full mass of the initial candidate is done using the SV Fit algorithm [2]. The algorithm is an event by event estimator of the true tau pair mass likelihood. The exact matrix element for the decay $\tau \to l\nu\nu$ and a phase space approach is used for τ_h decays and the nuisance parameters are integrated out. The algorithm produces a mass that is consistent with the true value with a width of 15-20%, it improves the separation of the Higgs signal from the irreducible Drell-Yan background over using the visible mass of the tau decay products.

PoS(ICHEP2012)067

4. Backgrounds

4.1 Drell-Yan to $\tau\tau$

Drell-Yan to $\tau\tau$ is a the largest background in all channels and categories and is irreducible. To estimate the contribution and produce a shape an embedding technique is used. The embedding technique takes Drell-Yan to $\mu\mu$ events and removes the muons and replaces them with generated tau leptons with the same kinematics as the original muon and allows them to decay. The advantage to this technique is obtaining information from the data for the additional event activity, specifically the jets and missing transverse energy. Uncertainties on this background range from 3-7% normalization in different categories and channels, in addition there is a 7% τ_h ID uncertainty and a 3% τ_h energy scale shape uncertainty on this background where appropriate.

4.2 W+Jets

W+Jets is the largest reducible background in $\tau_\mu - \tau_h$ and $\tau_e - \tau_h$ channels. This background comes about from a real lepton (e or μ) and an additional jet that fakes our τ_h candidate. It can be reduced by applying a cut on the transverse mass of the lepton + E_T^{miss} since the neutrino in real di-tau events will preferentially be collinear with the final state lepton due to the boosted nature of the tau decay and be back to back with the lepton in W events. This background is estimated using a high transverse mass sideband which is dominated by W events. Uncertainties on this background range between 10-30% depending on channel and category.

4.3 Multijet

Multijet background is common to all channels. It comes about from real muons in heavy flavor decays or jets faking an electron or τ_h candidate. For the $\tau_\mu - \tau_h$ and $\tau_e - \tau_h$ channels this background is estimated using an opposite sign to same sign method, the same sign region is dominated by QCD background. For the $\tau_e - \tau_\mu$ a fake rate method is used. Uncertainties range between 20-30% depending on channel and category.

4.4 Other Backgrounds

Other backgrounds include Drell-Yan to light leptons, $t\bar{t}$, di-Boson, and single top. Drell-Yan to light leptons is especially troublesome in the $\tau_e - \tau_h$ channel where there is a 2-3% chance that an electron can fake a τ_h candidate. These backgrounds are generally small and mostly come about from decays to a real tau pair in the event, they are taken from simulation and corrected for measured CMS cross sections where possible.

5. Results

Figures 1 and 2 show the $M_{\tau\tau}$ distributions for the 1-jet and VBF categories respectively compared to the background predictions. Only the three most performant channels are shown, $\tau_\mu - \tau_h$, $\tau_e - \tau_h$, and $\tau_e - \tau_\mu$, for the other channels and categories please see [2].

To search for the presence of a Higgs boson signal a binned maximum likelihood fit to the final tau pair invariant-mass spectrum is performed. The fit is done simultaneously across all channels

PoS(ICHEP2012)067

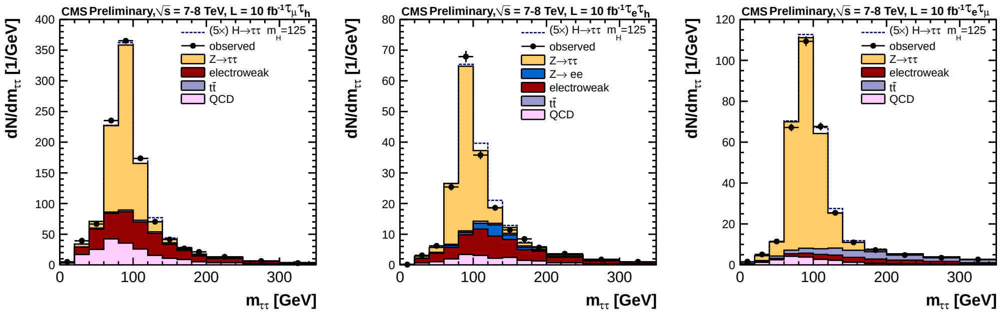

Figure 1: $M_{\tau\tau}$ distribution from the one-jet category, low and high p_T are combined, for the $\tau_\mu - \tau_h$ channel (left), $\tau_e - \tau_h$ channel (center), and $\tau_e - \tau_\mu$ channel (right).

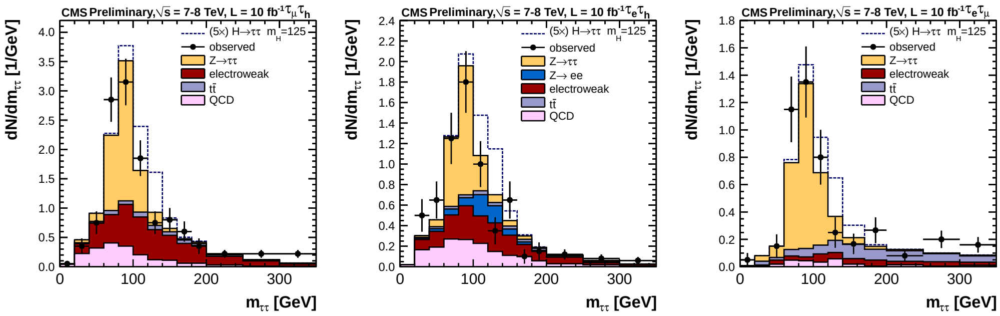

Figure 2: $M_{\tau\tau}$ distribution from the VBF category for the $\tau_\mu - \tau_h$ channel (left), $\tau_e - \tau_h$ channel (center), and $\tau_e - \tau_\mu$ channel (right).

and categories. Since no excess of events is observed after the fitting procedure 95% confidence level limits on the upper bounds of the Higgs boson cross section times branching ratio are set. This upper limit is plotted as a function of Higgs boson mass in Figure 3. The red line corresponds to the expected 95% exclusion and the black line the observed, the green and yellow bands correspond to one and two standard deviations respectively from the expected exclusion limit.

In comparison to the previous results [5] the sensitivity of the search has been improved significantly. This was achieved through improved object identification, further categorization into more categories, and improved mass resolution from an improved mass reconstruction algorithm.

6. Summary

A search for a SM Higgs Boson decaying to tau pairs is presented using a 10 fb^{-1} of CMS data. The data was collected in 2011 and 2012 with 4.9 fb^{-1} coming at 7 TeV center-of-mass energy and 5.1fb^{-1} at 8 TeV center-of-mass energy. No significant excess above the SM background expectation is observed. A 95% confidence level upper limit on the Higgs boson cross section times branching ratio is set in a mass range between 110 and 145 GeV. The observed 95% exclusion limit at m_H = 125 GeV is 1.06 times the standard model prediction. The result is consistent with either the presence of a SM Higgs boson or the background only hypothesis.

PoS(ICHEP2012)067

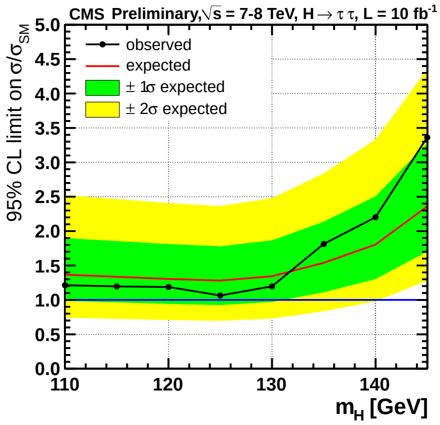

Figure 3: The expected one- and two-standard-deviation ranges are shown together with the observed 95% CL upper limits on the cross section times branching ratio, normalized to the SM expectation for Higgs boson production, as a function of m_H.

References

[1] CMS Collaboration, "Combined results of searches for the standard model Higgs boson in pp collisions at $\sqrt{s} = 7$ TeV", Phys. Lett. B 710 (2012) 26, doi:10.1016/j.physletb.2012.02.064

[2] CMS Collaboration, "Search For the Standard Model Higgs Boson Decaying to Tau Pairs in pp Collisions", CMS Physics Analysis Summary CMS-PAS-HIG-12-018, (2012)

[3] CMS Collaboration, "The CMS experiment at the CERN LHC", JINST 3 (2008) S08004, doi:10.1088/1748-0221/3/08/S08004.

[4] CMS Collaboration, "Performance of tau-lepton reconstruction and identification in CMS", JINST 7 (2012) P01001, doi:10.1088/1748-0221/7/01/P01001.

[5] CMS Collaboration, "Search for neutral Higgs bosons decaying to tau pairs in pp collisions at $\sqrt{s} = 7$ TeV", Phys. Lett. B 713 (2012) 68, doi:10.1016/j.physletb.2012.05.028.

PoS(ICHEP2012)067