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Search for Higgs Bosons Decaying to Tau Pairs in pp Collisions at $\sqrt{s}$ = 7 TeV

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A search for Higgs bosons in the decay to two τ leptons is described. The search is performed in the $e\mu$-, $\mu\mu$- $\mu\tau_h$- and $e\tau_h$-channels according to the subsequent decays of the τ leptons, where τ_h stands for a hadronic decay mode. The analysis strategies for a Standard Model (SM) and an MSSM based search are outlined. The results are based on part of the 2011 data sample corresponding to an integrated luminosity of 1.1 fb^{-1} recorded by the CMS experiment. No excess above the SM background expectation is observed in the reconstructed mass spectrum and upper limits on the Higgs boson cross section are set.

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1. Introduction

The Higgs boson [1] is the last missing piece of the Standard Model (SM) of particle physics and the search for it is in the spotlight of the CMS [2] physics programme. The SM Higgs boson is dominantly produced in the LHC via gluon fusion and with a lower cross section via vector boson fusion (VBF). In the Minimal Supersymmetric extension to the Standard Model (MSSM) [3] there are two Higgs doublets resulting in five physical Higgs bosons, two CP even (h, H), one CP odd (A) and two charged ($H^{\pm}$). The main production mechanisms for neutral MSSM Higgs bosons include gluon fusion and associated production with b quarks. The MSSM Higgs sector can be described at tree level on two parameters that are chosen to be the mass of the CP-odd Higgs m_A and the ratio of the vacuum expectation values of the two Higgs doublets denoted as $\tan\beta$. At higher orders, loop contributions from SUSY particles are non negligible and they are defined in specific benchmark scenarios. In this paper, the results are interpreted in the m_h^{max} scenario. The search for neutral Higgs bosons is performed by applying a common preselection of di-tau candidates and then applying specific event categorization which is tuned to the SM or MSSM Higgs boson search. Four different final states have been considered: *(i)* with a lepton and a hadronic tau, μ+τ_h and e+τ_h, *(ii)* with two leptons, e-μ and μ+μ. The final states with hadronic taus have the highest branching fraction, the e+μ final state has smaller branching fraction but also very low background contamination while the di-muon final state is challenging due to huge contamination of irreducible Z/γ^* background and it is the less sensitive one. Kinematical selections have been optimized to efficiently select signal events. To further reduce contamination from W + jets and $t\bar{t}$ backgrounds a topological selection based on the visible decay product of the taus and the missing transverse energy have been adopted. In order to discriminate between the $Z/\gamma^* \rightarrow \mu\mu$ and the $Z/\gamma^* \rightarrow \tau\tau \rightarrow \mu\mu$ processes a multivariate analysis has been implemented. The analyses presented in this report are documented in detail elsewhere [4].

2. Event Reconstruction and Selection

Muons in this analysis are reconstructed requiring the existence of a track in the tracker matched to segments in the muon system [5]. Additional criteria are applied to reject muons from decays in flight and heavy quarks. Electrons are identified by the presence of an electromagnetic cluster linked to a track reconstructed with a Gaussian Sum Filter algorithm [6]. The global event description provided by the Particle Flow (PF) reconstruction [7] is used to build higher level objects as hadronic decaying taus, jets and missing transverse energy. Hadronic taus are identified using the Hadron Plus Strips Algorithm (HPS) as described in [8]. Particle flow charged hadron candidates and particle flow photons located in η-strips in the vicinity of the charged hadrons are combined to form three categories of reconstructed τ_h lepton candidates: *(i)* to reconstruct one-prong decays, *(ii)* to reconstruct one-prong decays in association with one or more π^0's, *(iii)* to reconstruct three-prongs decays. Jets are reconstructed by combining Particle Flow candidates using the anti-kt algorithm [9] with a parameter of 0.5. Missing transverse energy is formed as the vectorial sum, changed in sign, of the momentum in the transverse plane of all the particles reconstructed by the PF Algorithm.

2.1 Event Categorization

Additional selections are applied to improve the sensitivity of specific modes. As far as the MSSM analysis is concerned, events are distinguished on the basis of a presence of at least one b-tagged jet with with $p_{\rm T} > 20\ GeV$. In the SM analysis events with two jets, with $p_{\rm T} > 30\ GeV$, in opposite hemispheres, a difference in η of at least 3.5 and invariant mass exceeding 350 GeV (VBF-like selections) [4] are separately from events with at most one jet.

3. Results

After event selection, a combined fit is performed on all final states using the visible mass shape. The visible mass is defined as the invariant mass of the visible tau decay products. The fit is constrained by background estimates and all systematic uncertainties are introduced as additional nuisance parameters. Figure 1 shows the reconstructed invariant mass of the tau visible decay products for the $\mu+\tau_h$ (left) and $e+\mu$ (right) final states in the categories with at least one b-tagged jets (top) and VBF-like selections (bottom).

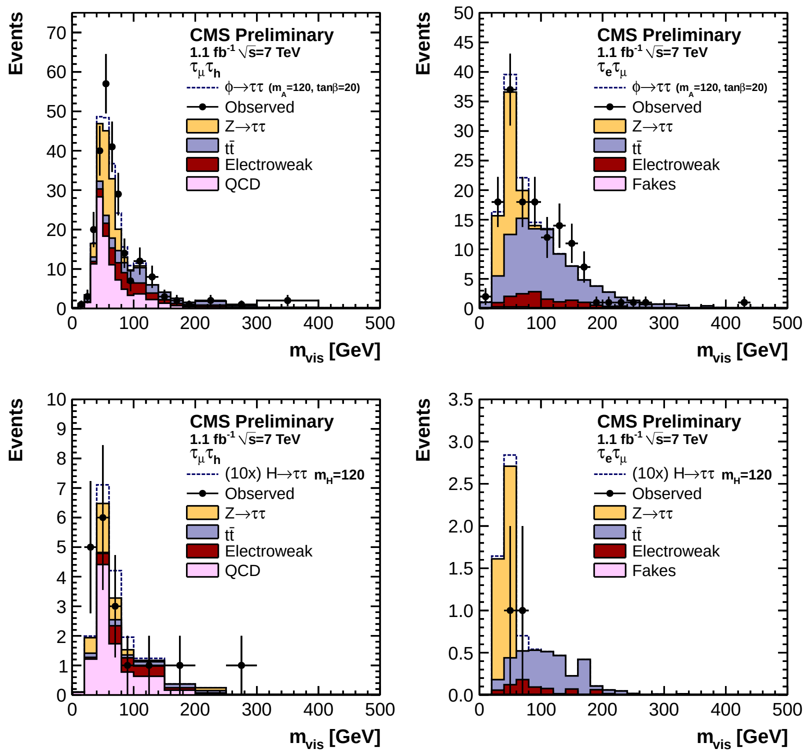

Figure 1: Reconstructed invariant mass of the tau visible decay products for the $\mu - \tau_h$ (left) and $e - \mu$ (right) final states in the categories with at least one b-tagged jets (top) and VBF-like selections (bottom).

No significant excess is observed in any of the final states under study. Therefore 95% CL upper limits are set for the Higgs boson production cross section. Figure 2 shows the cross section limits as a function of the mass in unity of SM Higgs boson cross-section (left) and the exclusion

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limit in the m_A-tanβ plane for the MSSM case (right). SM Higgs boson is excluded for cross sections higher than nine times the expected SM cross section while the MSSM case introduces new bounds for very high Higgs boson masses and also probes the low tanβ regime, approaching the LEP limits. Included in the plot is also a recent result by the D0 collaboration [10].

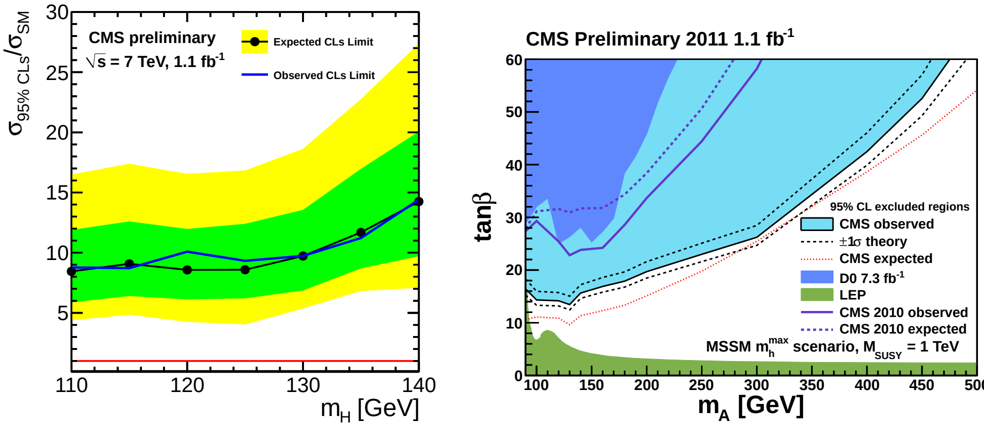

Figure 2: Cross section limits as a function of the mass, in unity of SM Higgs boson cross-section (left) and the exclusion limit in the m_A-tanβ plane for the MSSM case (right).SM Higgs is excluded for cross sections higher than nine times the expected SM cross section while the MSSM case introduces new bounds for very high Higgs masses and also probes the low tanβ regime, approaching the LEP limits. Included in the plot is also a recent result by the D0 collaboration.

4. Conclusions

Two searches for Higgs bosons in final states with tau leptons have been presented. The low mass SM Higgs boson search results to an exclusion of a production cross section higher than nine times the expected SM cross section with 1.1 fb^{-1} of data collected by the CMS detector in 2011. With the same luminosity stringent new bounds are set to the MSSM Higgs boson production as well. The excluded space in the m_h^{max} scenario for MSSM searches is shown in Fig. 2. For a Higgs boson mass of 500 *GeV* the tanβ limit is around 60, while for a mass of about 100 *GeV* the limit approaches the tanβ value of 14.

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