PROCEEDINGS OF SCIENCE

Higgs boson searches in the H→ττ channel

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A search for Higgs bosons in decay channels with two τ leptons in the final state is described. The search is performed in the H→ττ channel with the subsequent decay of the τ pairs into μμ, eμ, $\mu\tau_h$ and $e\tau_h$, where the subscript h indicated a hadronic decay of the τ lepton. The results are interpreted in the context of the Standard Model (SM) and a benchmark scenario of the Minimal Supersymmetric Standard Model (MSSM). The analysis is performed on $5fb^{-1}$ of data collected in 2011 with a centre of mass energy on 7TeV and on $5fb^{-1}$ of data collected in 2012 with a centre of mass energy of 8TeV, corresponding to a total integrated luminosity of $10fb^{-1}$ recorded by the CMS experiment. No evidence of signal is observed in the tau-pair invariant-mass spectrum. For the SM upper limits are set at 95% confidence level on the production cross section. The MSSM analysis is performed on 5 fb^{-1} 2011 data and an upper limit is set on the tanβ as a function of the pseudoscalar Higgs boson mass m_A.

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1. Introduction

In the Standard Model (SM) [1,2] the electroweak symmetry breaking is achieved by introducing a complex scalar doublet leading to the prediction of the Higgs boson [4-9]. Precision electroweak measurements constrain the SM Higgs mass to be m_H<158 GeV [10]. Previous CMS measurements using the 2011 dataset exclude the Higgs boson in the mass range 127.5-600 GeV [8,9]. For such a light Higgs boson the branching ration into τ-leptons is between 8% and 1.8%, making the H→ττ decay mode channel very promising (Figure 1).

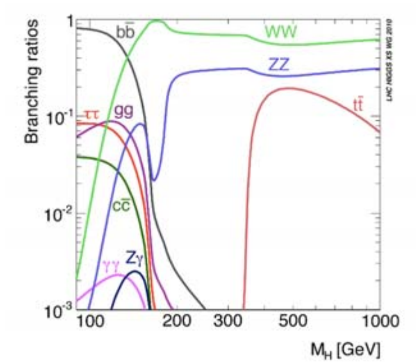

Figure 1.Branching ratios for the different decay modes of the Higgs boson in the SM as a function of the Higgs mass.

In addition the measurement of the H→ττ decay rate provides s test for the standard model prediction for the τ Yukawa coupling.

The analysis described here is using data from proton-proton collisions at $\sqrt{s} = 7$ and 8 TeV at the LHC. The data are collected in 2011 and 2012 corresponding to an integrated luminosity of about 10 fb^{-1} recorded by the CMS experiment. Four independent tau pair final states where one or both taus decay leptonically are studied: $e\tau_h$, $\mu\tau_h$, eμ and μμ where τ_h is used to indicate a reconstructed hadronic decay of a τ. The search strategy depends on the final state of the τ pair. In order to improve the τ pair mass resolution and to enhance the signal contribution, the selected τ pair events are classified according to the signature of the production mechanism (Figure 2).

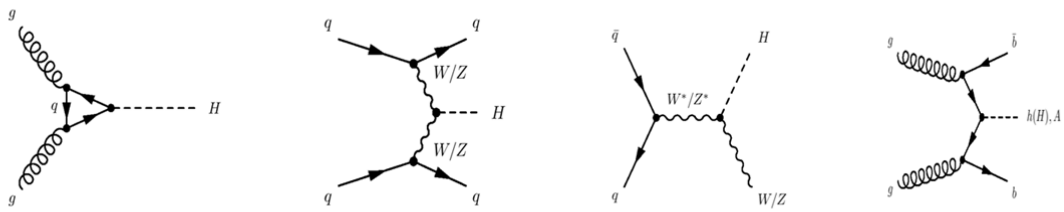

Figure 2.The Feynman diagrams for the main Higgs production processes in the SM and the MSSM. From right to left to right: gluon fusion, vector boson fusion (VBF), production associated with a vector boson and with b-quarks. The latter is enhanced in the MSSM.

In the Minimal Supersymmetric extension of the SM there are two scalar doublets resulting in five physical Higgs bosons. These are the light and heavy CP-even h and H, the CP odd A, and the charged Higgs bosons $H^{\pm}$. In lowest order the MSSM Higgs sector can be parameterized by the ratio of the two vacuum expectation values of the Higgs doublets, $\tan\beta \equiv v_2/v_1$, and the mass m_A of the CP-odd Higgs boson A. The production processes that are expected to be most relevant for early searches for MSSM Higgs bosons at the LHC are gluon-gluon fusion equivalent to the production of the SM Higgs boson and production in association with b-quarks. The Higgs boson cross section is proportional to the $\tan\beta^2$, therefore the production is enhanced for higher values of tanβ.

2. Event selection

The trigger selection requires a combination of electron, muon and tau trigger objects [11-13]. The identification criteria and transverse momentum thresholds of these objects were progressively tighten as the LHC instantaneous luminosity increased over the data-taking period. The lepton selection for all the decay channels is summarized in Table 1:

Decay channel	Lepton Selection
μμ	$p_T(\mu_{lead.}) > 20$ GeV $\lvert\eta(\mu)\rvert < 2.1$ $p_T(\mu_{sub.}) > 10$ GeV $\lvert\eta(\mu)\rvert < 2.1(2.4)$ $\Delta\varphi(\mu,\mu) > 2.0$ rad (not in VBF)
eμ	$p_T(\mu) > 10$ (20) GeV $\lvert\eta(\mu)\rvert < 2.1$ $E_T(e) > 20$ (10) GeV $\lvert\eta(e)\rvert < 2.3$
$\mu\tau_h$	$p_T(\mu) > 17$ (20) GeV $\lvert\eta(\mu)\rvert < 2.1$ $p_T(\tau_h) > 20$ GeV $\lvert\eta(\tau_h)\rvert < 2.3$
$e\tau_h$	$E_T(e) > 20$ (22) GeV $\lvert\eta(e)\rvert < 2.1$ $p_T(\tau_h) > 20$ GeV $\lvert\eta(\tau_h)\rvert < 2.3$

Table 1

In addition the presence of at least one good primary vertex in the event and opposite charge of the selected leptons is required. In the $\mu\tau_h$ and $e\tau_h$ channels a veto is applied for additional leptons of same flavor in order to suppress background from Drell-Yan events. Taus from Higgs boson decays are typically isolated from the rest of the event activity, whereas in the background misidentified taus are typically immersed in considerable hadronic activity. For each lepton candidate (e,μ or τ_h), a cone is constructed around the lepton direction at the event vertex. An isolation variable is constructed from the scalar sum of the transverse energy of all the reconstructed particles contained within the cone, excluding the contribution from the lepton candidate itself. Then a cut is applied on this isolation variable, I<0.1 or 0.15 depending on the lepton type and decay channel.

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To further discriminate the Higgs boson signal, especially from background events like W bosons in association with jets or $t\bar{t}$, in the eμ, $e\tau_h$ and $\mu\tau_h$ channels a restriction is applied on the transverse mass

$$m_T = \sqrt{2 \cdot p_T(l) \cdot MET(1 - \cos(\Delta\varphi_l, MET))}\text{ , where l=e,μ}$$

or to the linear combination :

$$p^{cut}{}_{\zeta}(\alpha) = p^{miss}{}_{\zeta} - \alpha \cdot p^{vis}{}_{\zeta},$$

where $p^{vis}{}_{\zeta}$ is the transverse momentum of the combined four vector of the two selected leptons projected onto their bisector in the transverse plane and $p^{miss}{}_{\zeta}$ is the projection of the transverse missing energy vector on the same bisector. The selection on m_T is chosen for the SM analysis in the $e\tau_h$ and $\mu\tau_h$ channels while in the eμ channel where the m_T is not well described and for the MSSM analysis the selection on p_ζ is chosen (Figure 4). The parameter α is chosen to optimise the signal significance.

In the case of the μμ final state in order to suppress the overwhelming background of Z→μμ events, a multivariate discriminator variable based on a Boosted Decision Tree (BDT) is used, which is trained to distinguish between three event classes, i.e. the Z→ττ→μμ and Z→μμ backgrounds and the Φ→ττ→μμ signal. The BDT combines information about the τ decay length and muon kinematics.

3.Event Classification

In order to further enhance the sensitivity of the search for Higgs bosons, we split the sample of selected events into mutually exclusive categories based on the jet multiplicity and topology. In this way the main processes of the Higgs production are exploited and the SM backgrounds processes further suppressed.

The event categories:

- Vector Boson Fusion (VBF): At least two jets with p_T>30GeV are required. In addition there must not be any b-tagged jets or any more jets with p_T>30GeV in the rapidity gap between the 2 leading jets. For further selection a MVA discriminator is constructed based on the dijet invariant mass, the Δη(jj) and Δφ(jj) between the 2 jets, the p_t of the ditau system, the p_T of the dijet system, the Δη between the visible di-tau system and the closest jet and the visible p_T of the ditau system.
- Boosted (1 Jet) Category: At least one jet with p_T > 30 GeV is required. Events must not be in the VBF category or include any b-tagged jets.
- B-Jet Category: At least one b-tagged jet with p_T>20 GeV and not more than one jets with p_T>30 GeV
- 0 Jets Category: The events in this category don't belong to any of the previous categories.

4. Tau-pair invariant mass reconstruction

The tau-pair mass is reconstructed using a maximum likelihood technique [14]. The algorithm computes the tau-pair mass that is most compatible with the moments of the visible tau decay products and the missing transverse energy reconstructed in the event. Free parameters, corresponding to the missing neutrino momenta, are subject to kinematic constrains and are eliminated by marginalization. The algorithm yields a tau-pair mass distribution consistent with the true value and a width of 15-20% (Figure 3).

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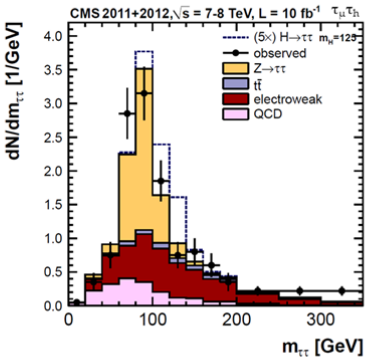

Figure 3.The ditau reconstructed mass for the VBF category in the μτh channel.

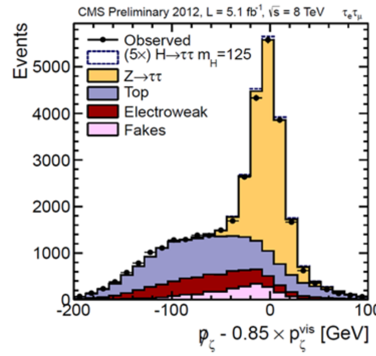

Figure 4.The selection variable pζ. The parameter α is optimised to give maximum signal over background significance.

5.Background contributions

The most important irreducible background comes from Z→ττ events. This contribution is estimated by an embedded sample. This sample is derived from a selection of Z→μμ events in data where each muon has been interpreted by a simulated tau. The inclusive yield of the embedded sample is normalised to the expected yield from Z MC, where the Z yield from the simulation is normalised according to control region of inclusive Z→μμ events.

For the QCD events a same sign sample is exploited. The SS (same sign)/OS (opposite sign) ratio is measured in a background enriched sample. This is achieved by inverting the lepton isolation cut. The QCD contribution in the signal region is then estimated by selecting SS events subtracting the other background contributions and multiplying with the SS/OS ratio.

The kinematics of the W+Jets background is taken from the simulation while the normalisation is taken from a W boson enriched control sample. This control region is defined by the m_T spectrum, where m_T >70 GeV. The extrapolation from the control region into the signal region is taken from the simulation after the other background contributions are subtracted. The Z+Jets background is estimated by the simulation corrected for fake rate.

The irreducible background from $t\bar{t}$ and di-boson production in each corresponding decay channel is taken from the simulation. The yields are monitored in a control region with an expected purity of $t\bar{t}$ events above 95% in each decay-channel. The yields of di-boson production are normalised to the NLO cross-section.

6. Results

To search for the presence of a Higgs boson signal in the selected events, we performed a binned maximum likelihood fit. In the eμ, $e\tau_h$ and $\mu\tau_h$ channels the fit is performed to the tau-pair invariant-mass spectrum. In the μμ case the fit is performed to the two-dimensional distribution of the tau-pair invariant mass and the dimuon visible mass. Systematic uncertainties are presented by nuisance parameters in the fitting process. The mass distributions show no evidence of signal. Therefore upper limits are set to the Higgs boson cross-section times the H→ττ branching fraction (σ_H x BR H→ττ) at 95% confidence level (CL) with respect to the SM Higgs expectation σ/σ_{SM} (Figure 5). For the calculation of the exclusion limits the modified frequentist construction CL_s [15-16] is used.

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In the MSSM 95% CL full CLs exclusion contour in the mA-tan b plane for the m_{Hmax} scenario [17] are shown in Figure 6 . These exclusion contours correspond to the data collected in 2011, corresponding to 4.6 fb^{-1}.

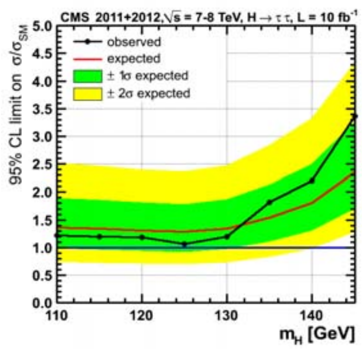

Figure 5.Expected and observed CLs 95% CL limits on the cross-section, normalised to the SM expectation for Higgs boson producrtion, as a function of m_H.

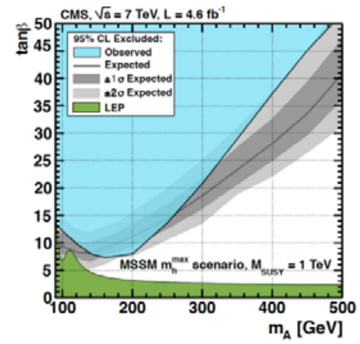

Figure 6.TheMSSM 95% CL limits on the m_A,tanβ plane.

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