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Tau Leptons and the Decay Higgs to tau tau at CMS

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Tau Leptons and the Decay $H \rightarrow \tau\tau$ at CMS

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Keywords: Tau lepton, Higgs, standard model, MSSM, CMS

1 The Tau Lepton

The τ is the heaviest known lepton. With a rest mass of 1776.82 MeV it can decay not only into muons or electrons but hadrons as well [1]. 62.65% of all tau leptons decay into ≥ 1 charged and ≥ 0 neutral hadrons. Because of its high mass, many theories on physics beyond the standard model (SM) predict large couplings of new particles to tau leptons.

At CMS [2], hadronically-decaying tau leptons (τ_h) are reconstructed using the hadron-plus-strips (HPS) algorithm [3] that produces all possible combinations of charged hadrons and π^0 candidates found within a jet. The combinations are ranked (or rejected) based on quality criteria such that in the end, one tau candidate per jet remains. Jets not originating from hadronic tau decays are discriminated against using the activity in the jet around the tau candidate. Leptonically-decaying tau leptons are reconstructed using standard CMS electron and muon reconstruction algorithms [4, 5].

2 Searches for Higgs Bosons Decaying into Tau Lepton Pairs

2.1 Search for the Standard Model Higgs Boson

The new boson with a mass near 125 GeV discovered by the ATLAS and CMS collaborations [6, 7] fits all SM predictions for a Higgs boson tested so far. A missing but essential information is the coupling of the new boson to fermions. The decay into two tau leptons is especially interesting because of both its large branching fraction and the lower background compared to the decay into b quarks.

The search for a Higgs boson decaying into a pair of tau leptons [8] is conducted targeting all tau decay channels individually for Higgs boson production via gluon fusion as well as vector boson fusion (VBF). In case of production in association with a vector boson (VH), only a subset of tau decay channels is analysed:

- $\ell + \mu\tau_h, \ell + e\tau_h, \ell + \tau_h\tau_h$ for WH ($\ell = e, \mu$),
- $\ell\ell + \mu\tau_h, \ell\ell + e\tau_h, \ell\ell + e\mu, \ell\ell + \tau_h\tau_h$ for ZH.

For each channel, separate kinematic selection requirements are imposed. These include transverse momenta (p_T) of the leptons, their pseudorapidity (η), as well as the (relative) isolation of each lepton. Following this basic selection, topological criteria are applied to reduce specific backgrounds (e.g., W+jets and $t\bar{t}$) involving missing transverse energy, and the number of identified b-quark initiated jets. The remaining events are then categorized, e.g. by the number of jets in the event, to maximize the sensitivity to a SM Higgs boson making use of the different production mechanisms.

The major backgrounds are estimated using data-driven techniques, while subdominant backgrounds from top-quark pairs, di-boson and single-top-quark production are modeled using simulation.

Since the neutrinos from tau decays can not be measured by the detector, a maximum likelihood technique is used to reconstruct the full invariant di-tau mass. This method takes both lepton momenta, the missing transverse energy and its covariance matrix into account [8].

Fig. 1. Left: Invariant mass of the di-tau system weighted by the ratio of signal (S) and signal+background (S+B) in each category of each channel. S and B are obtained in the interval containing 68% of the signal events [8]. Right: Likelihood scan as a function of the couplings κ_V and κ_f of vector bosons and fermions to the Higgs boson, respectively [8].

Figure 1 (left) shows the combined invariant mass of the di-tau system for the most sensitive categories. The combination of all channels yields an observed (expected) significance of 3.2σ (3.7σ) for a Higgs boson mass of 125 GeV. Figure 1 (right) depicts a likelihood scan in the parameter space of Higgs boson couplings to vector bosons and fermions. The best fit result is consistent with the SM prediction.

2.2 Investigating the Higgs Sector in the MSSM

The minimal supersymmetric extension of the standard model (MSSM) predicts two scalar doublets resulting in five physical Higgs bosons: three neutral (h , H and A) and two charged ($H^\pm$) ones [9, 10]. The dominant production mechanisms for neutral Higgs bosons are gluon fusion and b-quark associated production [11, 12]. The production cross section is dominated by b-quark associated production in case $\tan\beta$, the ratio of the vacuum expectation values of the two Higgs doublets, is large.

A search for neutral MSSM Higgs bosons [13] was performed in different decay channels of di-tau events: $e\tau_h$, $\mu\tau_h$, $e\mu$, $\mu\mu$ and $\tau_h\tau_h$. Similar to the previously-discussed search for a SM Higgs boson, selection criteria are applied to kinematic observables of the leptons as well as to variables constructed from missing transverse energy. Events are then categorized by the presence of b-quark initiated jets to exploit the different production mechanisms. The previously-described technique to reconstruct the full invariant di-tau mass is employed in this analysis as well. Backgrounds are estimated in the same manner as in the search for a SM Higgs boson outlined above.

The lack of evidence for a signal in the resulting invariant mass spectra leads to 95% confidence level (CL) limits on different benchmark models in the $m_A - \tan\beta$ plane as well as to model independent 95% CL upper limits on the production cross section of a scalar resonance ϕ decaying into a pair of tau leptons (cf. Fig. 2).

3 Summary

The reconstruction of tau leptons at CMS has been described as well as the searches for a SM and MSSM Higgs boson(s) decaying into pairs of tau leptons. While in case of the MSSM, no signal was observed and model dependent as well as model independent limits were set, a signal compatible with a SM Higgs boson of 125 GeV mass was found with a significance of 3.2σ . The couplings of this resonance to fermions and vector bosons were found to be in agreement with the SM prediction.

Fig. 2. Left: Expected and observed exclusion limits at 95% CL for the $m_h^{\text{mod}+}$ scenario. The allowed regions where the MSSM scalar Higgs boson h or H is compatible with the SM one are delimited by the hatched areas [13]. Center (right): 95% CL upper limit on cross section times branching fraction of gluon fusion (b-quark associated) production of a scalar resonance ϕ decaying into a tau lepton pair [13].

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