PROCEEDINGS OF SCIENCE

Search for the Higgs Boson Decaying into Taus Further Decaying into Same-flavour Leptons

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A search for the Higgs boson decaying into taus is presented. The focus is on the dimuon decay channel $H \to \tau\tau \to \mu\mu$. This channel is characterised by a small branching fraction of tau pairs decaying into pairs of same-flavour leptons, while the large $Z \to \mu\mu$ background demands for sophisticated background suppression methods that differ from the analyses in the other $H \to \tau\tau$ decay channels. The analysis presented here is based on the full dataset obtained at the CMS experiment in the years 2011 and 2012. The results are interpreted in terms of upper limits on the standard model Higgs boson production cross section.

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1. The Dimuon Channel in the Scope of the $H \to \tau\tau$ Analysis

Eight months after the observation of the Higgs boson with a mass near 125 GeV [1] in July 2012, first indications for couplings to tau leptons were found [2]. The $H \to \tau\tau$ channel is a prominent channel to search for Higgs bosons decaying into fermions (besides to $H \to b\bar{b}$, which has a higher branching ratio but suffers a from huge background contamination) and therefore to measure its fermionic couplings.

Several standard model (SM) background processes have to be considered. Z boson decays represent the most dominant background which differs from the Higgs signal mainly in the mass of the ditau system. Secondly, top pair production can lead to the same final states and is suppressed by vetoing b-tagged jets. Furthermore, diboson events (WW, WZ, and ZZ), W+jets events and QCD processes contribute to the backgrounds.

By categorising the events according to their jet multiplicity, the analysis gets sensitive to different Higgs boson production mechanisms. The gluon fusion process gives the highest production cross section at the LHC. Even though the vector boson fusion (VBF) has a rate that is about one order of magnitude smaller, the dedicated VBF category is the most sensitive one. This category profits from two forward jets and low hadronic activity in the central part of the detector, where the decay products of the Higgs boson are required to be selected, which gives a good distinction from SM background contributions. The gluon fusion process mainly contributes to categories with zero and one jet. In the one jet category, a jet recoils against the Higgs boson allowing for an improved missing transverse energy (MET) and ditau mass reconstruction. Because of its low signal ratio, the zero jet category is only used for constraining the backgrounds.

The presence of up to four neutrinos in the final state complicates the mass reconstruction of the ditau system. A likelihood-based algorithm is exploited to determine the most probable mass given the decay product kinematics and the MET and comparing them with the tau kinematics at the decay vertex.

The search for the standard model Higgs boson decaying into pairs of taus is performed in semi-leptonic ($\mu\tau_\mathrm{h}$, $e\tau_\mathrm{h}$), double-hadronic ($\tau_\mathrm{h}\tau_\mathrm{h}$) and double leptonic ($e\mu, \mu\mu$) channels. Mainly due to different branching fractions and different numbers of neutrinos in the final state and therefore different reconstruction potentials, the channels yield in different sensitivities.

1.1 MVA Selection of Signal-like Events and Background Estimation

In contrast to the other ditau channels, the dimuon analysis is not only dominated by the $Z \to \tau\tau$ background because of its signature that is very similar to the one of the Higgs signal, but also by the $Z \to \mu\mu$ background because of huge number of events. In order to suppress the overwhelming $Z \to \mu\mu$ background, multivariate analyses (MVA) have been applied.

A boosted decision tree is used to separate between Higgs signal and the sum of all expected backgrounds. The discrimination is achieved by variables, that mainly exploit the difference between processes with prompt muons and muons from tau decays. By selecting signal-like events based on a cut threshold on the resulting discriminator variable, mainly the $Z \to \mu\mu$ background can be reduced significantly. At the chosen working point, between 40% (1-jet) and 99% (VBF) of all background events are rejected, whereas the signal efficiency is between 90% (1-jet) and 30% (VBF). Even after this selection step, the $Z \to \mu\mu$ and $Z \to \tau\tau$ backgrounds remain the most

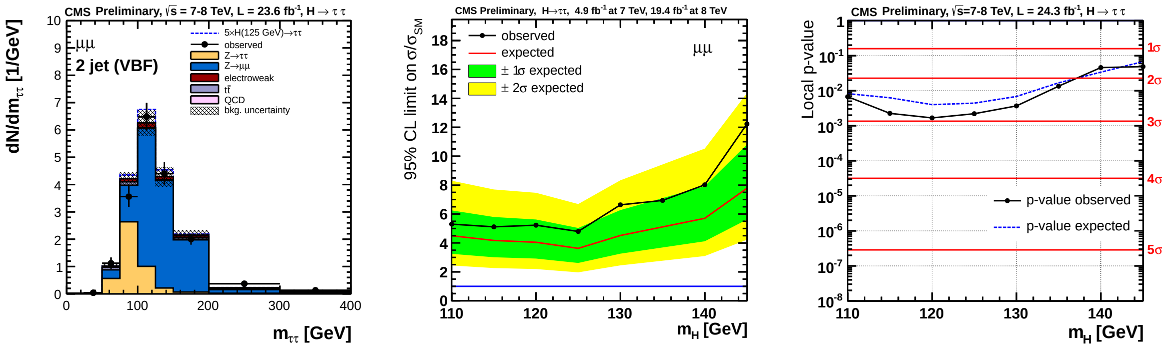

Figure 1: Final distribution of the reconstructed ditau mass in the VBF category (left) that is used together with the dimuon mass in a 2D approach to derive upper limits on the standard model Higgs boson production cross section as shown in (center) for the dimuon channel. The significance of the full $H \to \tau\tau$ analysis is shown in (right).

dominant backgrounds. The subsequent method of statistical inference accounts for these two backgrounds based on two mass variables. The visible mass, which does not take into account the neutrinos, gives a good separation against the $Z \to \mu\mu$ background, whereas the reconstructed ditau mass discriminates best between $H \to \tau\tau$ and $Z \to \tau\tau$ events, see Figure 1 (left). For theses reasons, a two-dimensional likelihood of the two mass variables is constructed.

For the $Z \to \mu\mu$ background, correction factors are derived via template fits to data in independent and signal-depleted control regions. Their application corrects both the shape and the normalisation of the background template. For the $Z \to \tau\tau$ background a data sample is taken which is dominated by $Z \to \mu\mu$ events. The measured muons are replaced by simulated taus ("embedding"). The QCD background is also derived from data. All other backgrounds are estimated from simulated events but then controlled in sideband regions, that are dominated by one of these backgrounds.

2. Results

The combined statistical inference in all categories in the dimuon channel leads to an observed (expected) upper limit on the standard model Higgs boson production cross section of 4.79 (3.62) times the standard model expectation at the mass hypothesis of 125 GeV at 95% confidence level, see Figure 1 (center). In combination with all $H \to \tau\tau$ channels, a maximum local significance of $2.93\,\sigma$ is observed at a mass of 120 GeV, see Figure 1 (right). A broad excess is seen which is compatible with the presence of a standard model Higgs boson of the mass 125 GeV.

References

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