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Search for $H \to \tau\tau$ in production processes in association with jets in CMS

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Summary. — A search for a light Higgs boson in the di-τ final state has been performed in CMS. Results, based on the 2011 data analysis and on an integrated luminosity corresponding to $4.6\,\mathrm{fb}^{-1}$ are presented and discussed along with the experimental issues related to the reconstruction of events in associated production processes.

PACS `14.80.Gt` – Higgs bosons and related particles.
PACS `14.80.Cp` – Non-standard-model Higgs bosons.
PACS `14.80.Da` – Supersymmetric Higgs bosons.

1. – Introduction

The analysis performed on the data collected by CMS during 2011 has excluded at 95% CL the possible existence of a SM-like Higgs boson in most of the mass region that has been explored, except for a window from 110 to 128 GeV.

In the search for a light Higgs boson, the di-τ state plays a crucial role, thanks to its sizeable branching ratio and to the expected relatively low background contaminations. In addition, couplings to tau leptons are favored in the Minimal Supersymmetric Standard Model (MSSM), making the di-τ channel sensitive to BSM Higgs bosons as well.

The production in association with jets, namely the Vector Boson Fusion (VBF) in the SM and b-quark associated production in the MSSM, presents a better signal-to-background ratio with respect to the gluon-fusion process, despite the low efficiency due to the selection of the signature jets.

The inclusion of these production processes in the combined analysis considerably improves the sensitivity of the Higgs search in the τ pair final state.

2. – Production processes

At the LHC the two most relevant SM Higgs production processes are the gluon fusion and the Vector Boson Fusion (VBF). While the former is dominant, the latter is characterized by the presence of light quark jets at large rapidities with a large rapidity separation and therefore large di-jet invariant mass: this peculiar signature is exploited in this analysis in order to suppress most of the backgrounds.

For the MSSM analysis, two production mechanisms are taken into account: the gluon fusion, which is dominant, and the b-quark associated production. The presence of b-jets in the final state constitutes a powerful handle for the background suppression.

For a light SM Higgs boson (with $m_H < 150$ GeV) the branching ratio into τ-leptons is sizable, around 10%, while in the MSSM the coupling to τ's is even enhanced by a factor $\tan^2 \beta$.

3. – Event selection

Three different final states of the di-τ pair have been studied in the present analysis: two semi-leptonic, where one tau decays into a lepton, either a muon or an electron, and the other one decays hadronically, $\mu\tau_h$, $e\tau_h$, and one cross flavored, fully leptonic, $e\mu$ [1,2].

The triggers used to select the events require the presence of $\mu\tau_h$, $e\tau_h$ or $e\mu$ pairs depending on the final state.

The selected events in the semi-leptonic channels must contain one isolated lepton (μ or e), in order to suppress the QCD background, and one τ hadronically decaying into pions (τ-jet) identified using the Hadron Plus Strip algorithm [3, 4], the ones in the fully leptonic channel must have both an isolated muon and an isolated electron. For all channels, cuts on the transverse momentum and on the pseudorapidity $|\eta|$ of the di-τ legs are applied in order to match the selection at the trigger level.

In addition, in order to suppress the W+Jets background a cut on the transverse mass between the lepton and the neutrino is applied.

3'1. *Event characterization: definition of categories.* – Since the contamination from the backgrounds, in particular Drell-Yann to di-τ, is overwhelming, the inclusive analysis, with no additional requirement on the jet topology, is limited in sensitivity.

For this reason, on top of the selection described above, the events have been further divided into mutually exclusive categories. The kinematic and topological variables related to the jets present in each event are the key to define these categories.

The cuts in the different categories have been chosen to select the different Higgs production processes, as shown above, and thus investigate phase space regions with particularly favorable signal-to-background ratio.

Three categories have been defined for the SM:

– <u>VBF:</u> at least two jets in two different hemispheres of the detector, with $p_T > 30$ GeV, large separation in η and large invariant mass. In addition, no other jet with $p_T > 30$ GeV in the rapidity region between these two jets.

– <u>Boosted:</u> one jet with $p_T > 150$ GeV. In addition, for the $e\mu$ channel, no b-tagged jet with $p_T > 20$ GeV.

– <u>0/1 Jet:</u> no more than one jet with $p_T > 30$ GeV, and if such a jet is present, it must have $p_T < 150$ GeV.

and two for the MSSM:

– <u>b-Tag:</u> at most 1 jet with $p_T > 30$ GeV, at least one b-tagged jet with $p_T > 20$ GeV.

– <u>No b-Tag:</u> at most 1 jet with $p_T > 30$ GeV, no b-tagged jet with $p_T > 20$ GeV.

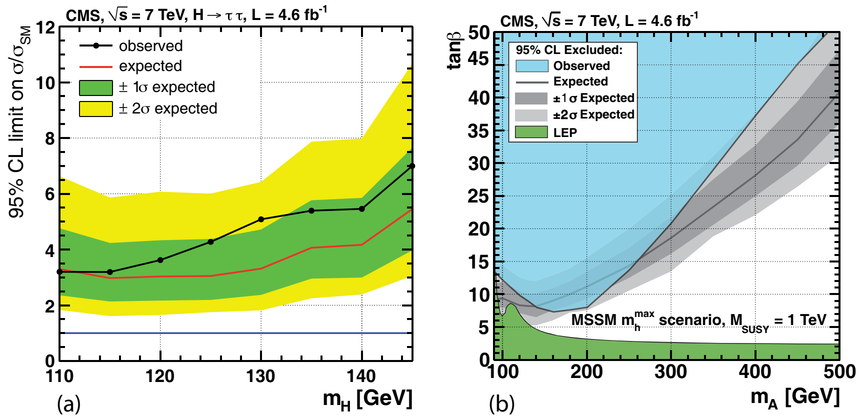

Fig. 1. – (a) The expected one- and two-standard-deviation ranges and the observed 95% CL upper limits on the cross section normalized to the SM expectation as a function of m_H. (b) Region in the parameter space of $\tan\beta$ versus m_A excluded at 95% CL in the context of the MSSM m_h^{max} scenario, with the effect of $\pm 1\sigma$ theoretical uncertainties shown.

4. – Results and conclusions

The results have been interpreted both in the SM and in the MSSM paradigms.

In the SM case, the analysis is not statistically sensitive yet, giving a 95% CL limit on $\sigma_H \cdot B_{\tau\tau}$ of 2.8 times the SM value at $m_H = 115\,\text{GeV}$ [2] (fig. 1(a)).

In the MSSM case, a previously unexplored region in the parameter space of $\tan\beta$ *versus* m_A, in the m_h^{max} scenario, reaching as low as $\tan\beta = 7.8$ at $m_A = 160\,\text{GeV}$, is excluded [2] (fig. 1(b)).

A search for neutral MSSM and SM Higgs bosons has been performed, using CMS data from *p*-*p* collisions at $\sqrt{s} = 7\,\text{TeV}$ at the LHC, corresponding to an integrated luminosity of $4.6\,\text{fb}^{-1}$. Three di-τ final states have been studied, $e\mu$, $e\tau_h$ and $\mu\tau_h$.

In order to enhance the sensitivity of the analysis the events have been split into different categories, exploiting the characteristic jet signature of the different Higgs production modes.

No excesses are evident in the mass spectrum thus upper bounds for the cross section times branching ratio have been extracted and then interpreted in both SM and MSSM paradigms. Limits have been computed per channel and per category and then combined together.

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