IL NUOVO CIMENTO Vol. 37 C, N. 6 Novembre-Dicembre 2014
DOI 10.1393/ncc/i2015-11866-9

Colloquia: LaThuile14

Search for the standard model H boson decaying to tau leptons and produced in association with a vector boson at CMS

C. Caillol(*) on behalf of the CMS Collaboration
IIHE, Université Libre de Bruxelles (ULB) - Brussels, Belgium

ricevuto il 31 Luglio 2014

Summary. — A search for the standard model (SM) H boson decaying to a pair of tau leptons and produced in association with a W or Z boson is presented using data collected in 2011 and 2012 with the CMS detector at the LHC. The topologies studied here represent three- or four-charged lepton final states, where the SM H boson is produced in association with the leptonic decay of a W or Z boson, respectively. The analyses use CMS collision data samples corresponding to integrated luminosities of $4.9\,\mathrm{fb}^{-1}$ collected at a centre-of-mass energy of $7\,\mathrm{TeV}$ and $19.7\,\mathrm{fb}^{-1}$ at $8\,\mathrm{TeV}$. No significant excess above the expected background is observed, resulting in exclusion limits between 0.96 and 8.9 times the expectation for the product of SM H cross section and tau pair decay branching fraction for H masses between 90 and $145\,\mathrm{GeV}$. The best fit of the observed $H \to \tau\tau$ signal cross section in associated production times branching fraction for $m_H = 125\,\mathrm{GeV}$ is -0.33 ± 1.02 times the SM expectation.

PACS `14.60.Fg` – Taus.
PACS `14.80.Bn` – Standard-model Higgs bosons.

1. – Introduction

The origin of the elementary particle masses, in particular those of the W and Z bosons, is described in the standard model (SM) by introducing a scalar field, called the Brout-Englert-Higgs field [1-3]. This field breaks the electroweak symmetry, and leads to the prediction of the so-called scalar H boson. Fermion masses are generated in the SM through Yukawa couplings to the H field. Searching for a scalar H boson decaying to a pair of tau leptons is an important probe of these Yukawa couplings.

On July 4, 2012, CMS and ATLAS Collaborations announced the discovery of a new boson with a mass around $125\,\mathrm{GeV}$, and compatible with the SM H boson [4, 5]. The excess was driven by two high-resolution decay channels: $\gamma\gamma$ and ZZ.

Data collected by the CMS detector during Run 1 amount to an integrated luminosity of $4.9\,\mathrm{fb}^{-1}$ and $19.7\,\mathrm{fb}^{-1}$ at a center-of-mass energy of 7 and $8\,\mathrm{TeV}$ respectively. The

(*) E-mail: `ccaillol@ulb.ac.be`

CMS Collaboration reported evidence for the 125 GeV H boson decaying to a pair of τ leptons [6], as well as a strong evidence for the direct decay of the 125 GeV H boson to fermions [7]. The search for the H boson decaying to a pair of tau leptons target the three dominant H production mechanisms at the LHC: gluon-gluon fusion, vector boson fusion and associated production with a vector boson. The analysis presented here reports about the search for a SM H boson decaying to a pair of tau leptons and produced in association with a vector boson — W or Z. H boson production in association with a vector boson suffers from a lower cross-section than the other two mechanisms, but is accessible experimentally because of the presence of high-momentum isolated leptons originating from the vector boson decays.

The analysis is divided into three sub-analyses according to the production mode and to the tau decay modes: $\ell+\ell'\tau_h$, $\ell+\tau_h\tau_h$ and $\ell\ell+L'L$, where τ_h denotes a hadronic tau decay, ℓ an electron or a muon, and L an electron, a muon or a hadronic tau. $\ell+\ell'\tau_h$ and $\ell+\tau_h\tau_h$ channels target a H boson produced in association with a W boson, while $\ell\ell+L'L$ analysis searches for a H boson produced in association with a Z boson. $\ell+\ell'\tau_h$ channels regroup $e+\mu\tau_h$, $\mu+e\tau_h$ and $\mu+\mu\tau_h$ final states; $\ell+\tau_h\tau_h$ channels regroup $\mu+\tau_h\tau_h$ and $e+\tau_h\tau_h$; and $\ell\ell+L'L$ channels regroup $ee+\tau_h\tau_h$, $ee+\mu\tau_h$, $ee+e\tau_h$, $ee+e\mu$, $\mu\mu+\tau_h\tau_h$, $\mu\mu+\mu\tau_h$, $\mu\mu+e\tau_h$ and $\mu\mu+e\mu$.

2. – Object selection and di-tau mass reconstruction

All particles are reconstructed and identified with a particle-flow algorithm [8], which combines the information collected by the different CMS subdetectors [9]. Hadronically decaying taus are reconstructed and identified from these particle-flow particles, using the Hadrons Plus Strips (HPS) algorithm [10]. The algorithm starts from particle-flow jets, and computes the τ_h four-momenta according to combinations of particle-flow charged and neutral particles compatible with specific hadronic tau decay modes. Quark and gluon jets are rejected with isolation criteria, while discriminators are applied to suppress electrons and muons misidentified as τ_h.

The visible mass between the tau leptons may be used for the statistical interpretation of results, but its power is attenuated by the fact that the tau neutrinos carry a non negligible momentum. The SVFIT algorithm computes the tau pair invariant mass $m_{\tau\tau}$ based on a maximum likelihood discriminator that combines the measured missing transverse energy with terms for the τ-lepton decay kinematics, and the missing transverse energy resolution. With respect to the visible mass, $m_{\tau\tau}$ enhances the separation between $H\to\tau\tau$ signal and $Z\to\tau\tau$ background, while improving the mass resolution.

$m_{\tau\tau}$ is the variable used for the statistical interpretation of results in $\ell\ell+L'L$ channels. In $\ell+L\tau_h$ channels, the visible mass between the tau leptons is however used as final observable, because of the presence of missing energy coming from the leptonic decay of the W boson.

3. – Event selection

Channels with two ℓ are based on a di-ℓ trigger, while $e+\tau_h\tau_h$ uses an $e+\tau_h$ trigger and $\mu+\tau_h\tau_h$ a single muon trigger.

$\ell\ell+L'L$ channels selection starts by identifying a Z candidate from a di-muon or di-electron pair, and assigning the other two leptons to the H boson. To form a Z candidate, the light leptons have to have an opposite-sign charge, and an invariant mass between 60 and 120 GeV. The two leptons composing the H candidate are required to have an

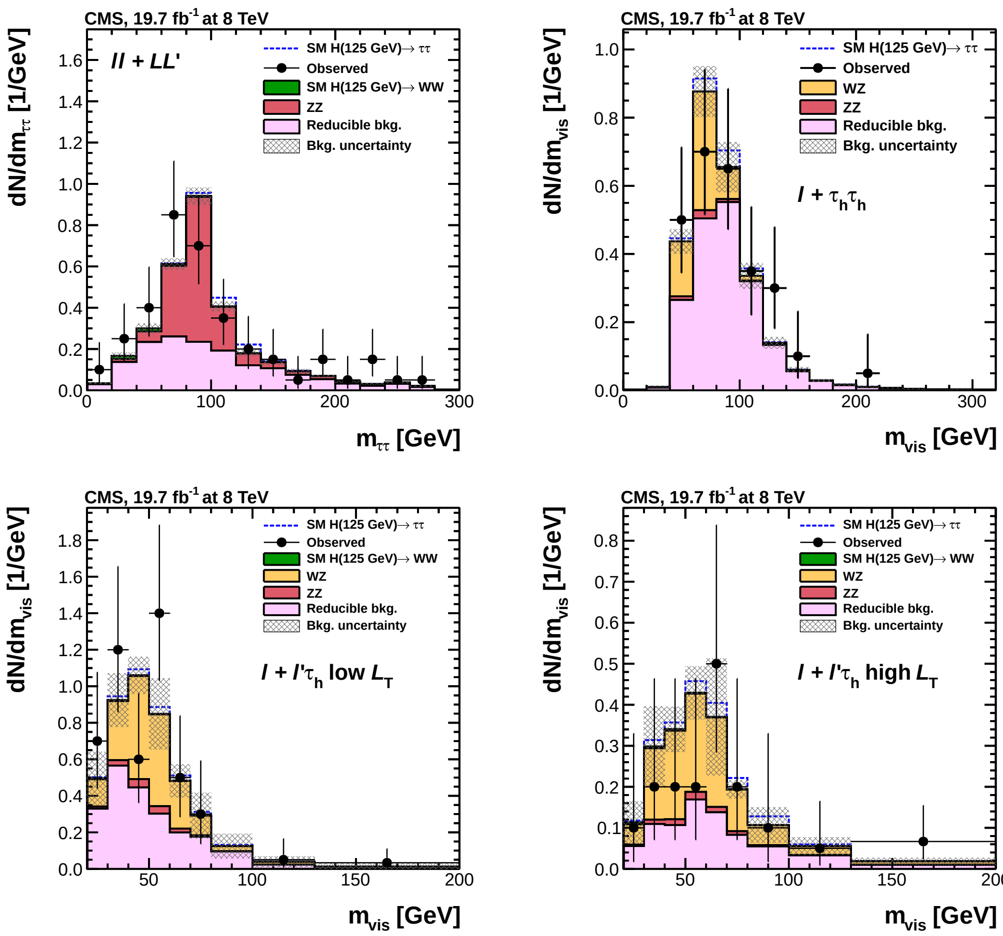

Fig. 1. – Observed and predicted $m_{\tau\tau}$ distributions in the $\ell\ell + L'L$ (top left); and m_{vis} distributions in the $\ell + \tau_h\tau_h$ (top right) channels and in the $\ell + \ell'\tau_h$ channels in the low L_T (bottom left) and high L_T (bottom right) categories, for the 8 TeV dataset.

opposite sign, and to satisfy isolation and identification criteria. Events with additional light leptons or b-tagged jets are vetoed from the analysis. In order to reduce the $Z+$jets background, a requirement on a minimal $L_T^{LL'} \equiv p_T^L + p_T^{L'}$ is imposed.

Background from Z boson and top quark pair production is strongly suppressed, in the $\ell + \ell'\tau_h$ channels, by requiring the two light leptons to have the same charge. In order to reduce further the backgrounds with misidentified leptons in these channels, the requirement $L_T \equiv p_T^{\ell} + p_T^{\ell'} + p_T^{\tau_h} > 80\,\text{GeV}$ is imposed for the 7 TeV dataset. At 8 TeV, the analysis is divided into two categories depending on the L_T value: low L_T ($L_T < 130\,\text{GeV}$) and high L_T ($L_T > 130\,\text{GeV}$).

$\ell + \tau_h\tau_h$ channels make use of a Boosted Decision Tree (BDT) [11] to reduce the contribution of backgrounds with misidentified leptons. The variables entering the tree are related to the kinematics of the $\tau_h\tau_h$ system and to the missing transverse energy.

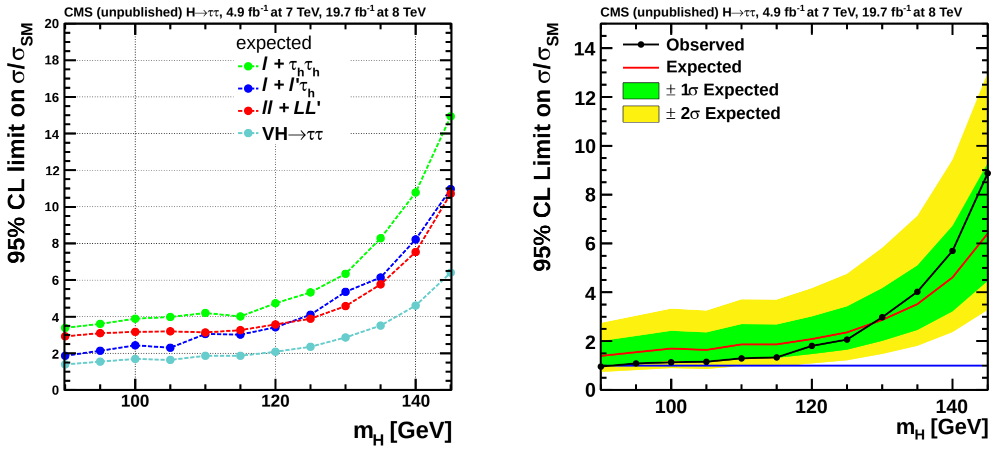

Fig. 2. – Expected 95% CL upper limit on the signal strength parameter in the background-only hypothesis for the $\ell\ell + L'L$, $\ell + \tau_h\tau_h$ and $\ell + \ell'\tau_h$ channels and their combination (left); and observed and expected 95% CL upper limit on the signal strength parameter in the background-only hypothesis for the combined $H \to \tau\tau$ in associated production search at 7 and 8 TeV (right). The bands show the expected one- and two-standard-deviation probability intervals around the expected limit.

4. – Background estimation and systematic uncertainties

Irreducible background arises from ZZ diboson production in $\ell\ell + L'L$ channels, and from WZ and ZZ diboson productions in $\ell + L\tau_h$ channels. Its shape and its normalization are estimated from Monte Carlo simulations.

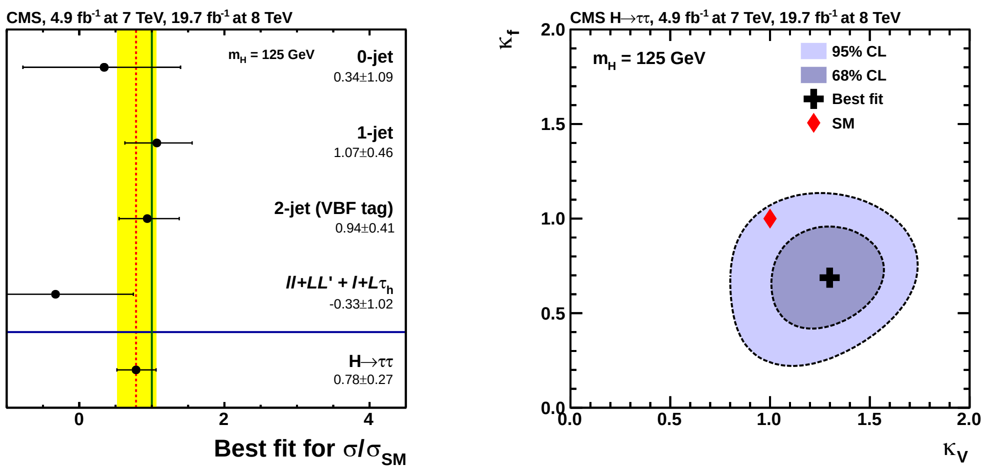

Fig. 3. – Best fit of the observed $H \to \tau\tau$ signal cross section in associated production times branching fraction for $m_H = 125\,\text{GeV}$ (left); and likelihood scan in the (κ_V, κ_f) parameter space for $m_H = 125\,\text{GeV}$ (right).

The reducible background is composed of all processes for which at least one jet is misidentified as a prompt lepton. In the $\ell + L\tau_h$ channels, the reducible background comes from QCD multijets, $W + \text{jets}$, $Z + \text{jets}$, $W + \gamma$, $Z + \gamma$, and $t\bar{t}$ production, while in the $\ell\ell + L'L$ channels, it comes from $WZ + \text{jets}$, $Z + \text{jets}$ and $t\bar{t}$ production. This background is estimated from data, using a method that relies on the measurement of the misidentification probabilities of a jet as a lepton. The latter are estimated in independent control regions, enriched in QCD multijets, $W + \text{jets}$ or $Z + \text{jets}$ events, and are parameterized as a function of the lepton transverse momentum in the $\ell + \tau_h\tau_h$ channels, and as a function of the transverse momentum of the jet closest to the lepton in the $\ell + \ell'\tau_h$ and $\ell\ell + L'L$ channels. The control regions are defined in such a way as to be signal-free. Reducible background contribution in the signal region is estimated by weighting sideband events for which at least one of the leptons does not pass the isolation or identification requirements, with a factor depending on the misidentification probabilities. A smooth template shape is achieved in $\ell\ell + L'L$ channels by relaxing the isolation criteria.

Theoretical uncertainties affect the expected signal yield, and experimental uncertainties are related to the identification of physics objects, or to the background estimation. The detailed list of uncertainties considered in this analysis may be found in [6].

5. – Results

Figure 1 shows the final distributions for $\ell\ell + L'L$, $\ell + \tau_h\tau_h$ and $\ell + \ell'\tau_h$ channels, using the 8 TeV dataset. Data are in agreement with SM background expectation, and upper limits at 95% confidence level (CL) between 0.96 and 8.9 are established on the product of H boson cross-section and tau decay branching fraction for H masses between 90 and 145 GeV, as shown in fig. 2. In the limit setting procedure, $H \to WW$ process in associated production, which contributes mainly to the $\ell\ell + e\mu$ channels, is considered as a background in order to probe H decay to tau leptons only. The distributions are combined in a binned likelihood that involves the observed and the expected number of events in each bin. The signal strength modifier μ, which multiplies the number of signal events expected in the SM, is a free parameter of the fit, while the systematic uncertainties are represented by nuisance parameters.

Combining $H \to \tau\tau$ searches in gluon-gluon fusion and vector boson fusion production with $H \to \tau\tau$ searches in associated production with a vector boson improves the sensitivity of the analysis by 5%. The best fit of the observed $H \to \tau\tau$ signal cross section in associated production times branching fraction for $m_H = 125$ GeV is $\hat{\mu} = -0.33 \pm 1.02$ times the SM expectation, while it is $\hat{\mu} = 0.78 \pm 0.27$ for $H \to \tau\tau$ in all production modes, as shown in fig. 3 (left). Associated production channels also have a significant impact on the measurement of κ_V and κ_f, which are the parameters that quantify the ratio between the measured and the SM value for the coupling of the H boson to vector bosons and fermions. Figure 3 (right) shows a likelihood scan in the (κ_V, κ_f) parameter space for $m_H = 125$ GeV, and illustrates that the result is compatible with the SM expectation.

* * *

The author is supported by the FNRS (Belgium).

REFERENCES

[1] Englert F. and Brout R., *Phys. Rev. Lett.*, **13** (1964) 321, doi:10.1103/PhysRevLett.13.321.
[2] Higgs P. W., *Phys. Lett.*, **12** (1964) 132, doi:10.1016/0031-9163 (64) 91136-9.
[3] Guralnik G. S., Hagen C. R. and Kibble T. W. B, *Phys. Rev. Lett.*, **13** (1964) 585, doi:10.1103/PhysRevLett.13.585.
[4] CMS Collaboration, *Phys. Lett. B*, **716** (2012) 30, doi:10.1016/j.physletb.2012.08.021.
[5] ATLAS Collaboration, *Phys. Lett. B*, **716** (2012) 1, doi:10.1016/j.physletb.2012.08.020.
[6] CMS Collaboration, *JHEP*, **05** (2014) 104, doi:10.1007/JHEP05(2014)104.
[7] CMS Collaboration, *Nat. Phys.*, **10** (2014) 557, doi:10.1038/nphys3005.
[8] CMS Collaboration, *Particle-Flow Event Reconstruction in CMS and Performance for Jets, Taus and* E_T^{miss}. CMS Physics Analysis Summary CMS-PAS-PFT-09-001 (2009).
[9] CMS Collaboration, *JINST*, **3** (2008) S08004, doi:10.1088/1748-0221/3/08/S08004.
[10] CMS Collaboration, *JINST*, **7** (2012) P01001, doi:10.1088/1748-0221/7/01/P01001.
[11] Voss H., Hocker A., Stelzer J. and Tegenfeldt F., *"TMVA, the toolkit for multivariate data analysis with ROOT"* in *XI International Workshop on Advanced Computing and Analysis Techniques in Physics Research* (2007). PoS ACAT:040.