IL NUOVO CIMENTO Vol. 34 C, N. 6 Novembre-Dicembre 2011
DOI 10.1393/ncc/i2011-11074-9

Colloquia: IFAE 2011

# Preliminary results on Supersymmetric Higgs searches at LHC

M. Tosi
*Università di Padova and INFN, Sezione di Padova - Padova, Italy*

(ricevuto il 29 Luglio 2011; pubblicato online il 6 Dicembre 2011)

**Summary.** — In supersymmetric theories scenarios, the production of neutral Higgs scalars or pseudo-scalar particles and their following decay to pairs of tau leptons or b-quarks is greatly enhanced for a large part of the parameters space of the theory, not yet excluded by previous experiments. Preliminary results of the search of these states performed by the CMS experiment at the LHC on the data collected in 2010 are shown.

PACS 14.80.Da – Supersymmetric Higgs bosons.

## 1. – Introduction

The minimal supersymmetric extension to the Standard Model (MSSM) requires the presence of two Higgs doublets, which turn to five massive Higgs bosons: a light neutral scalar (h), two charged scalars ($H^{\pm}$), a heavy neutral $CP$-even state (H) and a neutral $CP$-odd state (A).

This report presents the searches for MSSM Higgs bosons in pp collisions at a center of mass energy of 7 TeV, using a data sample collected in 2010 corresponding to 36 $\mathrm{pb}^{-1}$ of integrated luminosity recorded by the Compact Muon Solenoid (CMS) experiment.

## 2. – Physics objects reconstruction at CMS

Details of the CMS detector and its performance can be found elsewhere [1]. Muons are reconstructed [2] with a simultaneous global fit performed on hits in the tracker and the muon system. Electrons are reconstructed [3] from clusters of energy deposits in the electromagnetic calorimeter that are matched to tracker hits. Jets and the missing transverse energy ($\not{E}_T$) are reconstructed using Particle Flow (PF) objects [4]. Jets are clustered with the anti-$k_T$ algorithm [5] with a cone size $R = 0.5$. Tau candidates are reconstructed [6] using tracking and calorimeter information. The algorithm which shows the best performance in terms of fake rate and efficiency, by taking full advantage of the PF techniques for reconstructing individual charged hadrons and photons, is the Hadron plus Strips (HPS). This algorithm employs cuts on the multiplicity and invariant mass of charged hadrons and neutral pions reconstructed in a narrow cone, together with vetoing other particles of transverse momentum, $p_T$, above a fixed threshold within the jet.

## 3. – Search for neutral MSSM Higgs bosons

The most interesting production processes for early searches for MSSM neutral Higgs bosons at the LHC, which contribute to $\mathrm{pp} \to \Phi + \mathrm{X}$, with $\Phi = \mathrm{h}$, H or A, are the *gluon-gluon fusion*, for small and moderate values of $\tan\beta$ (defined as the ratio of vacuum expectation values of two Higgs fields), and the production in *association with bottom quarks*, which constitutes the dominant mechanism for large values of $\tan\beta$. The best experimental signature for this search at hadron colliders is the tau-pair decay mode of neutral Higgs bosons, having a branching ratio of about 10% for large $\tan\beta$.

In this analysis [7], three final states where one or both taus decay leptonically are used: $\mathrm{e}\tau_h$, $\mu\tau_h$, and $\mathrm{e}\mu$.

The triggers used to select events are based on the presence of an electron and/or a muon trigger object, and also special triggers requiring the presence of both a lepton and a charged track with an accompanying calorimeter pattern consistent with a $\tau$ decaying hadronically were adopted for the $\mathrm{e}\tau_h$ and $\mu\tau_h$ channels.

The Higgs boson signal can be distinguished from backgrounds via the *full mass* of the tau-pair, $M_{\tau^+\tau^-}$. In this analysis the $M_{\tau^+\tau^-}$ reconstruction is done by a novel likelihood technique, which is built from three terms: the tau decay phase-space, the probability density in the tau transverse momentum, parameterized as a function of the tau pair mass, and the compatibility of the sum of neutrino momenta with the measured value of the missing transverse energy. The product of the three terms is maximized with respect to the free parameters in the likelihood functions: the energies and directions of the neutrinos produced in the tau decays. The momenta of visible tau decay products are fixed to their measured values. The algorithm yields a tau pair mass solution for each event, with mean consistent with the true value and nearly Gaussian resolution. For a Higgs of mass $130\,\mathrm{GeV}/c^2$ a resolution of $\sim 21\%$ is attained. The observed reconstructed tau-pair mass distribution for all three channels is shown in fig. 1.

The analyzed data is in agreement with the expectation for SM background processes, and no evidence for a Higgs signal is seen in the tau-pair mass spectrum. Therefore, an upper bound on the product of the Higgs boson cross-section and the tau-pair branching fraction, $\sigma_\Phi \cdot \mathrm{BR}_{\tau\tau}$, is set. The limit is computed as function of the mass of the pseudo-scalar Higgs, $m_\mathrm{A}$, by fitting the $M_{\tau^+\tau^-}$ distribution observed in all decay channels with shape templates for different Higgs mass hypotheses, obtained from Monte Carlo simulation.

A Bayesian approach with a uniform prior on $\sigma_\Phi \cdot \mathrm{BR}_{\tau\tau}$ is used to set the limit. Systematic uncertainties on fit parameters corresponding to background normalization, signal efficiencies and energy scales are represented by nuisance parameters and removed by marginalization. Moreover, for a given mass hypothesis $m_\mathrm{A}$ the product of signal acceptance times efficiency is computed by weighting acceptances and efficiencies for h, H and A bosons according to the expected cross-section. Higgs cross-sections entering the weighting procedure are computed for $\tan\beta = 30$ and both the two production processes are considered. Differences between scalar and pseudoscalar Higgs bosons and between the $\mathrm{gg} \to \Phi$ and $\mathrm{b\bar{b}} \to \Phi$ production mechanisms ($\leq 10\%$) are taken into account as systematic uncertainty. These upper limits, interpreted in the MSSM parameter space of $\tan\beta$ *versus* $m_\mathrm{A}$ in the $m_\mathrm{H}^{max}$ benchmark scenario [8], turn to bounds on $\tan\beta$, shown in fig. 1.

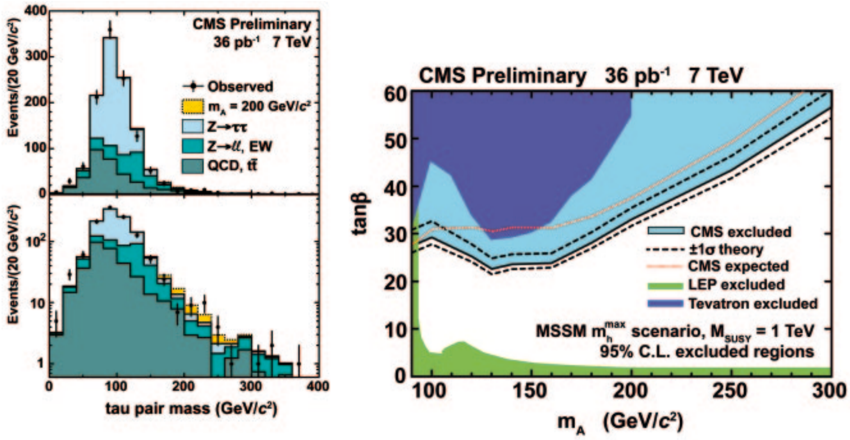


Fig. 1. – (Colour on-line) Left: the reconstructed tau-pair *full mass* distribution on linear (above) and logarithmic (below) scales, for the sum of the $e\tau_h$, $\mu\tau_h$, and $e\mu$ final states, comparing the observed distributions (points with error bars) to the sum of the expected backgrounds (shaded histograms). The contribution from a Higgs boson signal ($m_A = 200\,\text{GeV}/c^2$) is also shown, with normalization corresponding to the 95% upper bound on $\sigma_\Phi \cdot BR_{\tau\tau}$. Right: region in $\tan\beta$ *versus* $m_A$ parameter space excluded at 95% CL in the context of the MSSM $m_h^{max}$ scenario [8], by the $36\,\text{pb}^{-1}$ of data collected by CMS in 2010. Theoretical uncertainties are represented by black dashed lines, enclosing the observed limit. The other shaded regions show the 95% CL excluded regions from LEP (green) and Tevatron (purple) experiments.

## 4. – Search for charged MSSM Higgs in top quark events

With data collected by CMS in 2010, the search for the charged Higgs boson is done in the low $H^\pm$ mass regime, when $m_{H^\pm} < m_{top}$. In such a scenario, the Higgs boson may be produced in top quark decays, $t \to H^\pm b$, and then it preferentially decays in the channel $H^\pm \to \tau\nu_\tau$, for large $\tan\beta$ (greater than 20). This behavior alters the SM model prediction of the tau lepton production in $t\bar{t}$ events, which could be directly observable in this decay channel, by measuring the cross sections and branching ratios of SM processes and comparing the results with the MSSM predictions. The search for an excess of tau lepton events in the $t\bar{t}$ sample is therefore a direct way to search for beyond SM physics.

The final state studied in this analysis [9] is a sub-set of the di-lepton $t\bar{t}$ sample, $t\bar{t} \to (l\nu_l)(\tau\nu_\tau)b\bar{b}$ (with $l = e, \mu$), where events are requested to have one isolated muon or electron ($p_T > 20\,\text{GeV}/c$ and $|\eta| < 2.1$ for muons, $E_T > 30\,\text{GeV}$ and $|\eta| < 2.5$ for electrons), at least two jets ($p_T > 30\,\text{GeV}/c$ and $|\eta| < 2.4$) missing transverse energy ($\not{E}_T > 40\,\text{GeV}$), and one tau lepton ($p_T > 20\,\text{GeV}/c$ and $|\eta| < 2.4$). In this analysis only hadronically decaying tau leptons are considered. A good agreement between data and SM expectations is found at various levels of the events selections. In 2010, the inclusive lepton dataset was collected with triggers which require events to have at least one electron or muon above a minimum transverse momentum threshold.

The largest background contributions in this analysis come from the irreducible $t\bar{t}$ di-tau channel, and from tau fakes, where one jet fakes the tau. The main background ($\tau$-fake) is from events where one W boson is produced in association with jets, and from $t\bar{t} \to W^- bW^+\bar{b} \to l\nu_l qq'b\bar{b}$ events. The data driven method used in the estimate of the $\tau$-fake background is described in ref. [10]. The non–$\tau$-fake backgrounds,

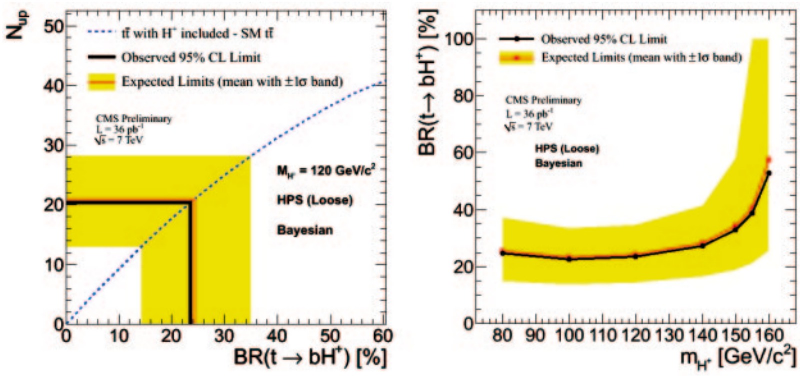


Fig. 2. – Left: relation between $N_{up}$ and the upper limit on BR(t $\rightarrow$ H$^+$b) for the observed and the expected limit with $\pm 1\sigma$ error band shown in yellow for $M_{\mathrm{H}^\pm} = 120\,\mathrm{GeV}/c^2$, where BR(H$^+ \rightarrow \tau\nu$) = 1 is assumed. Right: upper limit on BR(t $\rightarrow$ H$^+$b) assuming BR(H$^+ \rightarrow \tau\nu$) = 1 as a function of $M_{\mathrm{H}^+}$. The yellow band shows the $\pm 1\sigma$ band around the expected limit.

like $\mathrm{Z}/\gamma^* \rightarrow \tau^+\tau^-$, single top production, di-bosons, and the part of the SM $\mathrm{t\bar{t}}$ background not included in the $\tau$-fake background are estimated from MC together with the corresponding statistical (due to the limited number of MC events) and systematic uncertainties.

The expected number of SM events is $N_{\mathrm{SM}} = 38.3 \pm 2.5 \pm 5.8$. Signal events from $\mathrm{t\bar{t}} \rightarrow \mathrm{W^\pm b H^\mp \bar{b}}$ (WH) and $\mathrm{t\bar{t}} \rightarrow \mathrm{H^\pm b H^\mp \bar{b}}$ (HH) processes at $M_{\mathrm{H}} = 120\,\mathrm{GeV}/c^2$, obtained using the SM $\mathrm{t\bar{t}}$ cross-section, $\sigma_{NNLO} \approx 165 \pm 10\,\mathrm{pb}$ [11], and forcing the decay $\mathrm{t} \rightarrow \mathrm{H^+ b}$ for the top quark(s), assuming BR( H $\rightarrow \tau\nu_\tau$) = 1, are $N^{\mathrm{HW}}_{\mathrm{MSSM}} = 68.1 \pm 1.9 \pm 9.1$ and $N^{\mathrm{HH}}_{\mathrm{MSSM}} = 66.5 \pm 1.8 \pm 9.7$, respectively.

Of the 40 events found in the data, 16(24) events are in the $\mathrm{e}\tau(\mu\tau)$ final state, consistent with expectations. Therefore, the number of candidate events found are in agreement with the expected SM event yield and the upper limit at 95% CL on the excess of the events ($N_{up}$) in addition to the expected SM background is obtained by using a Bayesian method with the flat signal strength prior. All systematic uncertainties for selection efficiencies on signal events and for estimated background events ($\tau$-fake background, *i.e.* tau identification efficiency, $\tau$ mis-identification, jet energy and $\not\!\!E_T$ scale, MC cross sections, lepton trigger, identification and isolation efficiencies, integrated luminosity) are given as the input for the exclusion limit calculation. Assuming that a possible excess of events is due to the $\mathrm{t} \rightarrow \mathrm{bH^+}$, $\mathrm{H^+} \rightarrow \tau^+\nu_\tau$ decays with BR($\mathrm{H^+} \rightarrow \tau\nu_\tau$) = 1, on BR($\mathrm{t} \rightarrow \mathrm{bH^+}$) is then obtained from the following equation:

$$
\begin{aligned}
N_{up} = {} & N^{\mathrm{HW}}_{\mathrm{MSSM}} \cdot 2(1-x) \cdot x + N^{\mathrm{HH}}_{\mathrm{MSSM}} \cdot x^2 + \\
& + \left(N^{l\tau}_{\mathrm{SM\ t\bar{t}}} + N^{ll}_{\mathrm{SM\ t\bar{t}}} + N^{l\mathrm{qq}'}_{\mathrm{SM\ t\bar{t}}}\right) \cdot (1-x)^2 + \\
& - \left(N^{l\tau}_{\mathrm{SM\ t\bar{t}}} + N^{ll}_{\mathrm{SM\ t\bar{t}}} + N^{l\mathrm{qq}'}_{\mathrm{SM\ t\bar{t}}}\right)
\end{aligned}
\tag{1}
$$

where $x = \mathrm{BR}(\mathrm{t} \rightarrow \mathrm{bH^+})$, and the numbers $N^{l\tau}_{\mathrm{SM\ t\bar{t}}}$, $N^{ll}_{\mathrm{SM\ t\bar{t}}}$ and $N^{l\mathrm{qq}'}_{\mathrm{SM\ t\bar{t}}}$ are the expected SM backgrounds in $\mathrm{t\bar{t}}$ events. Figure 2 shows the relation between $N_{up}$ and the upper limit on BR($\mathrm{t} \rightarrow \mathrm{bH^+}$) for the observed and the expected limits (mean with $\pm 1\sigma$ band). Figure 2 shows the upper limit on BR($\mathrm{t} \rightarrow \mathrm{bH^+}$) assuming BR($\mathrm{H^+} \rightarrow \tau\nu_\tau$) = 1 as a function of $M_{\mathrm{H}^+}$. The yellow band shows the $\pm 1\sigma$ band around the expected limit.

## 5. – Conclusions

Results of the MSSM Higgs boson searches obtained by using $36\,\mathrm{pb}^{-1}$ of pp collision at $\sqrt{s} = 7\,\mathrm{TeV}$ data, recorded by the CMS experiment in 2010 are reported.

No evidence for neutral MSSM Higgs bosons production is observed in the distribution of the *full mass* of the tau leptons pair. A limit on Higgs boson cross-section times the branching fraction for the decay into tau pairs is thus set. The observed limit, interpreted in terms of the MSSM parameter space, excludes a significant region in the MSSM $\tan\beta$ *versus* $m_{\mathrm{A}}$ plane not previously explored by experiments at the TeVatron [12] and at LEP [13].

No significant excess for a charged MSSM Higgs boson in top quark events is found with respect to expectations. The number of candidate events found are in agreement with the expected SM event yield and an upper limit on the branching ratio is set: $\mathrm{BR}(\mathrm{t} \to \mathrm{H}^+\mathrm{b}) \sim 0.25$–$0.28$ for charged Higgs masses between 80 and $140\,\mathrm{GeV}/c^2$, when assuming $\mathrm{BR}(\mathrm{H}^+ \to \tau\nu_\tau) = 1$.

REFERENCES


[1] Adolphi R. *et al.*, *JINST*, **0803** (2008) S08004.
[2] CMS Collaboration, *Performance of muon identification in pp collisions at $\sqrt{s} = 7$ TeV*, in CMS-PAS-MUO-10-002 (2010).
[3] CMS Collaboration, *Electron reconstruction and identification at $\sqrt{s} = 7$ TeV*, in PAS-EGM-10-004 (2010).
[4] CMS Collaboration, *Commissioning of the Particle-Flow Reconstruction in Minimum-Bias and Jet Events from pp Collisions at 7 TeV*, in CMS-PAS-PFT-10-002 (2010).
[5] Cacciari M., Salam G. P. and Soyez G., *JHEP*, **04** (2008) 063.
[6] CMS Collaboration, *Performance of tau reconstruction algorithms in 2010 data collected with CMS*, in PAS-TAU-11-001 (2011).
[7] CMS Collaboration, *Phys. Rev. Lett.*, **106** (2011) 231801, arXiv:1104.1619v1 [hep-ex] (2011).
[8] Carena M. *et al.*, *Eur. Phys. J. C*, **26** (2003) 601607.
[9] CMS Collaboration, *Search for the charged Higgs boson in the $e\tau$ and $\mu\tau$ dilepton channels of top quark pair decays in pp collisions at $\sqrt{s} = 7$ TeV*, in CMS-PAS-HIG-11-002 (2011).
[10] CMS Collaboration, *Prospects for the measurement of the* $\mathrm{t}\bar{\mathrm{t}}$ *cross section ratio $e\tau$ and $\mu\tau$ dilepton channel in pp collisions*, in CMS-PAS-TOP-08-004 (2008).
[11] Kidonakis N., *Higher-order corrections to top-antitop pair and single top quark production*, arXiv:0909.0037 [hep-ph] (2009).
[12] The CDF Collaboration, The D0 Collaboration, The Tevatron New Physics Higgs Working Group, *Combined CDF and D0 upper limits on MSSM Higgs boson production in tau-tau final states with up to 2.2 $fb^{-1}$*, arXiv:1003.3363v3 [hep-ex] (2010).
[13] ALEPH, DELPHI, L3, OPAL Collaborations. The LEP Working Group for Higgs Boson Searches, *Eur. Phys. J. C*, **47** (2006) 547.