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Search for MSSM and NMSSM Higgs bosons with the CMS detector

Christian Veelken[a] on behalf of the CMS Collaboration

[a] *Laboratoire Leprince-Ringuet, École Polytechnique, 91128 Palaiseau, France*

Abstract

Searches for charged and neutral Higgs bosons in the context of the Minimal Supersymmetric Standard Model (MSSM) and in the context of the Next–to–Minimal Supersymmetric Standard Model (NMSSM) are presented. The analyses are based on proton–proton collision data recorded by the CMS experiment at $\sqrt{s}$ = 7 TeV and $\sqrt{s}$ = 8 TeV center–of–mass energy in 2011 and 2012, respectively, corresponding to integrated luminosities of up to 4.9 fb^{-1} and 20.7 fb^{-1}. No evidence for further Higgs bosons in addition to the discovered SM–like Higgs boson of mass $\approx$ 125 GeV is found and stringent exclusion limits are derived.

Keywords:

1. Introduction

A Higgs boson of mass $\approx$ 125 GeV has been discovered at the LHC [1, 2]. The measured spin, branching–fractions and CP quantum numbers of the new boson are compatible with the standard model (SM) predictions [1]. Besides being "the" Higgs boson predicted by the SM, the discovered boson may as well be one of multiple Higgs bosons, which are predicted to exist in supersymmetric theories.

The Minimal Supersymmetric Standard Model (MSSM) contains two Higgs doublet fields, giving rise to five physical Higgs boson states, of which two are charged (H^+, H^-) and three are neutral: the light and heavy scalars h and H plus the pseudo–scalar A. The mass of the light scalar Higgs boson is bound to be below the Z mass a tree level in the MSSM, but can reach up to $\mathcal{O}$(135 GeV) via radiative corrections. In order to achieve m_h = 125 GeV, sizeable radiative corrections are required, necessitating a large stop mass and/or mixing [3].

The need for fine–tuning of the radiative corrections is reduced in the Next–to–Minimal Supersymmetric Standard Model (NMSSM). The presence of an additional complex singlet field allows to achieve a mass of 125 GeV for the lightest scalar Higgs boson with moderate radiative corrections, by means of mixing between the Higgs doublet and singlet fields [4]. The NMSSM predicts the existence of five neutral (three scalars h_1, h_2, h_3 plus two pseudo–scalars a_1 and a_2) plus two charged Higgs bosons (H^+, H^-).

A search for charged and neutral MSSM Higgs bosons and for light scalar NMSSM Higgs bosons is presented. The searches are based on integrated luminosities of up to 4.9 fb^{-1} plus 20.7 fb^{-1}, recorded by the CMS experiment in proton–proton collisions at $\sqrt{s}$ = 7 TeV and $\sqrt{s}$ = 8 TeV center–of–mass energy in 2011 and 2012, respectively.

2. Search for light neutral NMSSM Higgs bosons

A search for light NMSSM Higgs bosons a in the mass range $0.25 < m_a < 3.55$ GeV (below twice the tau mass) is performed in the channel where a pair of a bosons decays to four muons [5]. The light NMSSM Higgs bosons may for example be produced via the decay of a scalar Higgs boson h, as illustrated in Fig. 1.

[1] See proceedings of this conference for latest results.

The analysis is not restricted to a specific model, however, and the results of the search are applicable to a broad spectrum of new physics scenarios. The search is based on 20.7 fb^{-1} of data collected at $\sqrt{s}$ = 8 TeV.

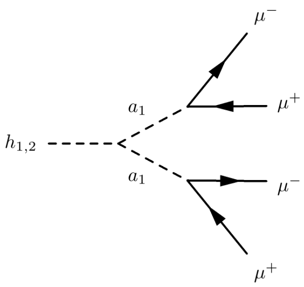

Figure 1: Production on a pair of light NMSSM Higgs bosons a via decay of a scalar Higgs boson h with subsequent decay of the pair of a bosons to four muons.

Events are selected by requiring the presence of two pairs of muons. The muons considered for the pairs are required to pass $P_T > 8$ GeV and $|\eta| < 0.9$. Each pair is required to contain two muons of opposite charge and mass $m_{\mu\mu} < 3.55$ GeV. At least one of the muons is required to satisfy $P_T > 17$ GeV, in order to trigger the event. All four muons need to be compatible with originating from a common vertex. The muons are required to be isolated with respect to charged particles originating from this vertex. The second (first) muon belonging to the pair is excluded when computing the isolation of the first (second) muon. The masses of both muon pairs are further required to be compatible within the experimental resolution.

The main backgrounds to this analysis are due to $b\bar{b}$ decays to muons and to direct production of J/Ψ pairs. The backgrounds are estimated from data, using events in which the two muon pairs have different masses (*cf.* Fig. 2 left).

One event is observed in the signal region (*cf.* Fig. 2 right), compatible with the background expectation, amounting to 3.8 ± 2.1 events.

In the absence of evidence for a signal, stringent limits on cross–section times branching ratio, $\sigma(pp \to 2a) \cdot \mathcal{B}^2(a \to 2\mu)$, are set. The 95% confidence level (CL) limit is shown in Fig. 3.

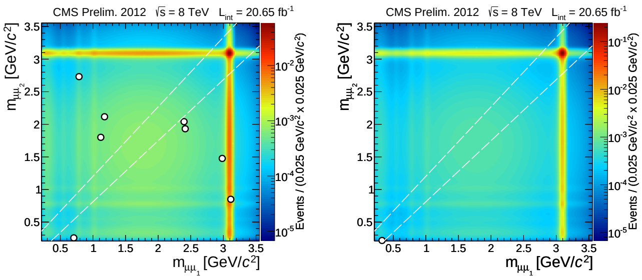

Figure 2: Distribution of masses of the two muon pairs in the sideband region used for background estimation (left) and in the signal region (right). Events selected in the data are represented by open circles. 8 (1) events are observed in the sideband (signal) region.

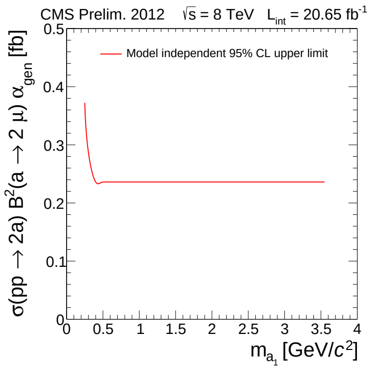

Figure 3: 95% CL upper limit on cross–section times branching ratio times appectance. The acceptance, α_{gen}, corresponds to the probability for signal events to contain four muons of $P_T > 8$ GeV and $|\eta| < 0.9$, with at least one of muon satisfying $P_T > 17$ GeV, on generator level. Quoting the limit in terms of α_{gen} allows to interpret the results of the search in different physics models, requiring only the recalculating of the acceptance specific to that model.

3. Search for charged MSSM Higgs bosons

A search for charged Higgs bosons is performed in the mass range $m_{H^+} < m_t - m_b$. The charged Higgs bosons in signal events are produced via decays of top quarks, $t \to H^+ b$, in $pp \to t\bar{t}$ events. The decay channel considered in the search is $t\bar{t} \to H^+ b\, W^- b \to c\bar{s} b\, \mu\nu b$ [6]. The decay of charged Higgs bosons to $c\bar{s}$ is sensitive in particular to low values of $\tan\beta$, defined as the ratio of vacuum expectation values of the two Higgs doublet fields. The search is based on a dataset corresponding to an integrated luminosity of 19.7 fb^{-1}, recorded at $\sqrt{s}$ = 8 TeV center–of–mass energy.

The events are selected by requiring the presence of at least four jets of $P_T > 30$ GeV and $|\eta| < 2.4$, a well identified and isolated muon of $P_T > 25$ GeV and $|\eta| < 2.1$ plus missing transverse energy, $\not{E}_T > 20$ GeV. At least two of the jets are required to pass b–tag criteria. The events are triggered on the presence of the isolated muon. Events containing further electrons or muons of

$P_T > 10$ GeV and $|\eta| < 2.5$, passing loose identification and isolation criteria, are rejected.

Note that the production rate of $t\bar{t}$ pairs does not depend on the presence or absence of a charged Higgs boson signal. What changes in the presence of a signal are the types of particles that are produced in the decays of the top quarks (*cf.* Fig. 4). The handle to separate the $t\bar{t} \to H^+b\,W^-b \to c\bar{s}b\,\mu\nu b$ signal from the SM $t\bar{t} \to W^+b\,W^-b \to q\bar{q}'b\,\mu\nu b$ background is the mass of the two non–b–tagged jets.

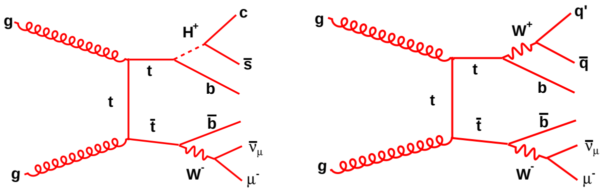

Figure 4: Production of top quark pairs with subsequent decay of the top quarks to charged Higgs boson plus W boson, $t\bar{t} \to H^+b\,W^-b \to c\bar{s}b\,\mu\nu b$ (signal, left), and to two W bosons, $t\bar{t} \to W^+b\,W^-b \to q\bar{q}'b\,\mu\nu b$ (SM background, right).

A kinematic fit [7] is used to improve the resolution on the di–jet mass, M_{jj}, in order to enhance the signal–to–background separation. Inputs to the fit are the measured momenta of the muon, the b–tagged and non–b–tagged jets and the reconstructed $\not{E}_{\mathrm{T}}$, plus their respective resolutions. The mass of muon plus $\not{E}_{\mathrm{T}}$ is constrained to the W boson mass and the masses of one b–tagged jet plus muon plus $\not{E}_{\mathrm{T}}$ (the other b–tagged jet plus the two non–b–tagged jets) is constrained to the top–quark mass. The solution yielding the lowest χ^2 in the fit is used as criterion to decide which one of the b–tagged jets to pair with muon plus $\not{E}_{\mathrm{T}}$ and to resolve ambiguities in case an event contains more than four jets or more than two jets passing the b–tagging criteria. The distribution of M_{jj} reconstructed by the kinematic fit in signal and background events is shown in Fig. 5 (left).

No evidence for a signal is observed in the distribution of the di–jet mass (*cf.* Fig. 5 right). 95% CL upper limits on the branching fraction $\mathcal{B}(t \to H^+b)$ in the range 2.0–6.0% are set for charged Higgs boson masses of 90–160 GeV. The limit is shown in Fig. 6. It is computed assuming that all charged Higgs bosons decay to $c\bar{s}$.

4. Search for neutral MSSM Higgs bosons

A search for neutral MSSM Higgs bosons, denoted by Φ, is performed in the tau pair decay channel [8].

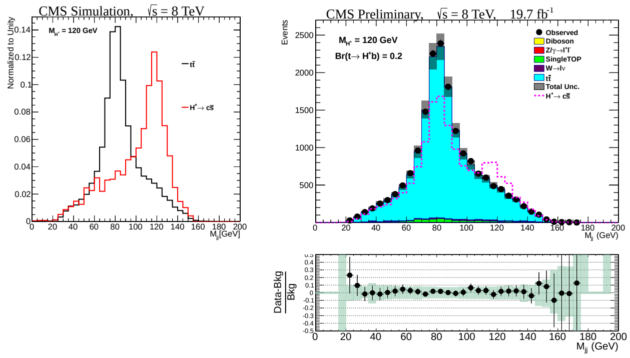

Figure 5: Left: Distribution of M_{jj} expected for charged Higgs signal and SM $t\bar{t}$ background events, reconstructed by the kinematic fit. Right: Di–jet mass distribution observed in data, compared to the expectation for background (solid histogram) respectively signal plus background (dashed line) hypothesis.

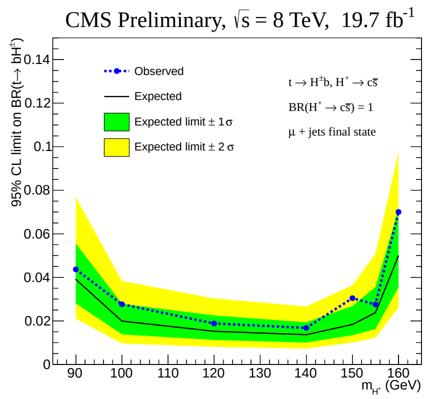

Figure 6: 95% CL upper limit on the branching ratio $t \to H^+b$. The limit is computed assuming $\mathcal{B}(H^+ \to c\bar{s}) = 100\%$.

The $\tau_h\tau_h$, $e\tau_h$, $\mu\tau_h$, $e\mu$ and $\mu\mu$ final states are included in the analysis, covering a branching fraction of 96.9% of the tau pair [2]. The analyzed dataset corresponds to an integrated luminosity of 4.9 fb^{-1} recorded at $\sqrt{s}$ = 7 TeV plus 19.7 fb^{-1} recorded at $\sqrt{s}$ = 8 TeV center–of–mass energy.

Selected events are analyzed in two event categories, based on the presence respectively absence of a b–tagged jet of $P_T > 20$ GeV and $|\eta| < 2.4$ in the event. The two event categories provide sensitivity to two different production mechanisms: gluon–gluon fusion and b–associated production, illustrated in Fig. 7. The gluon–gluon fusion (b–associated production) process

[2] We denote by τ_h the hadronic decay of a tau.

is the dominant production mode for neutral MSSM Higgs bosons in case $\tan\beta$ is small (large). The presence of a b–tagged jet also improves the signal–to–background ratio, thereby improving the overall sensitivity of the analysis.

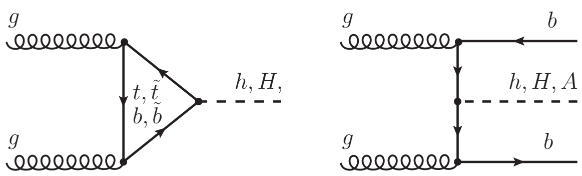

Figure 7: Production of neutral MSSM Higgs bosons Φ via gluon–gluon fusion ($gg \to \Phi$, left) and b–associated production ($gg \to \Phi b$, right). In the case of b–associated production one of the b–quarks is typically outside the acceptance of the detector.

The presence of a signal is inferred by analyzing the distribution of the tau pair mass, $m_{\tau\tau}$. The mass is reconstructed by a likelihood based algorithm, developed by CMS [9], with a resolution of typically 20%.

The distributions of $m_{\tau\tau}$ observed in the b–tag and no–b–tag category of the $\tau_h\tau_h$, $e\tau_h$, $\mu\tau_h$, $e\mu$ and $\mu\mu$ channels are shown in Fig. 8.

No evidence for a signal is observed in the CMS data. Corresponding 95% CL upper limits on cross–section times branching ratio are set, separately for each of the two production processes gluon–gluon fusion and b–associated production. The limits are shown in Fig. 9.

The limits are interpreted in the m_h^{max} scenario [10] of the MSSM and exclude a large region in m_A–$\tan\beta$ parameter space, as shown in Fig. 9.

Limits for other MSSM benchmark scenarios proposed in Ref. [11] have been computed after the conference. The results are published in Ref. [12].

5. Summary

Searches for neutral and charged Higgs bosons in the context of the MSSM and NMSSM have been presented. No evidence for a signal is observed in the CMS data so far. Stringent upper limits on corresponding cross–sections and branching–ratios have been set.

The searches for MSSM and NMSSM Higgs bosons presented at the ICHEP 2014 conference are complemented by earlier results of searches for supersymmetric Higgs bosons performed by CMS: searches for single light NMSSM Higgs bosons in the decay channel to muons [13], searches for charged MSSM Higgs bosons in decays to taus [14], and searches for neutral MSSM Higgs bosons in decays to a pair of b–quarks [15] and to muons [16].

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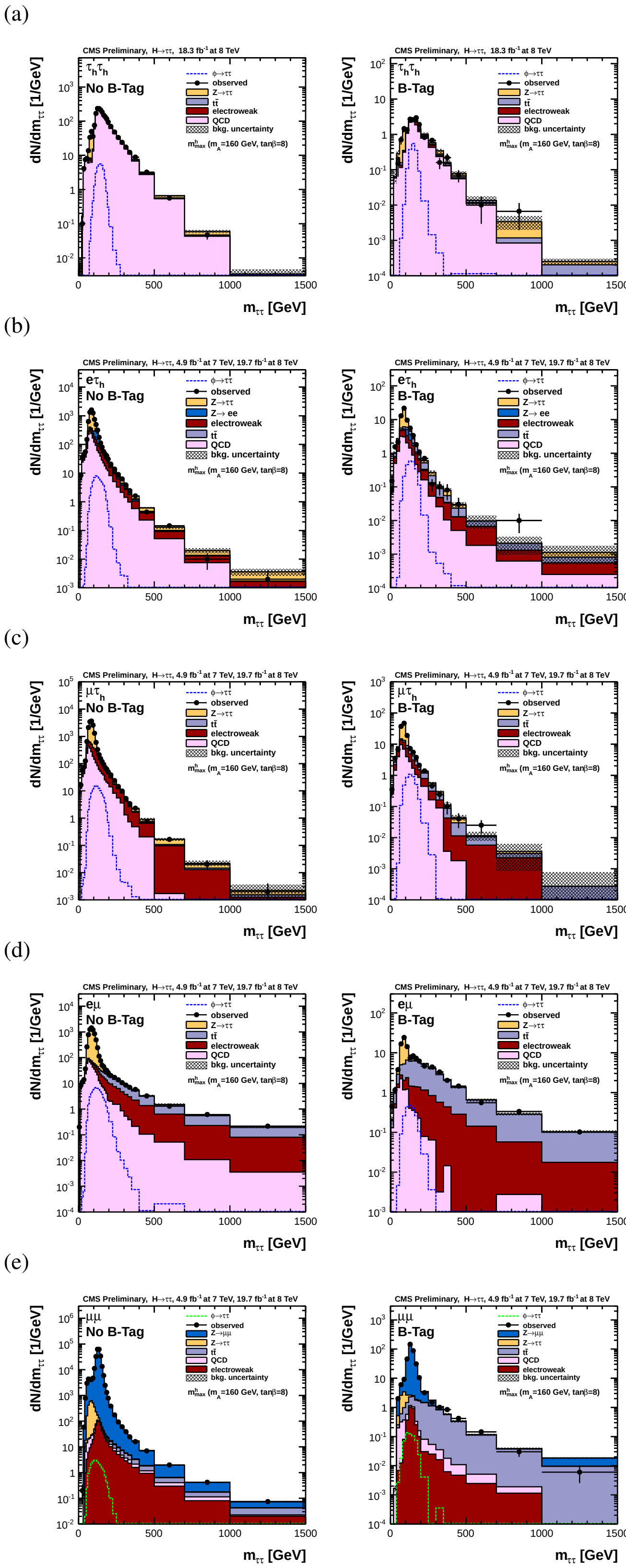

Figure 8: Distribution of the tau pair mass, $m_{\tau\tau}$, observed in the no–b–tag (left) and b–tag (right) category of the search for neutral MSSM Higgs bosons, in the $\tau_h\tau_h$ (a), $e\tau_h$ (b), $\mu\tau_h$ (c), $e\mu$ (d) and $\mu\mu$ (e) final state, compared to the SM expectation.

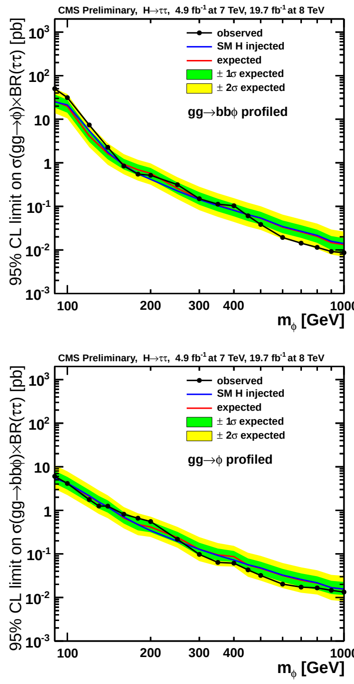

Figure 9: 95% CL upper limits on the production cross–section for neutral MSSM Higgs bosons, $\sigma(pp \to \Phi)$, times the branching ratio for the decays into tau pairs, $\mathcal{B}(\Phi \to \tau\tau)$, for gluon–gluon fusion (top) and b–associated production (bottom). Expected limits have been computed for two cases: for the assumption that there is no Higgs $\to \tau\tau$ signal (neither MSSM nor SM) present in the data (red line) and assuming that there is no MSSM, but a SM Higgs of mass ≈ 125 GeV present (blue line).

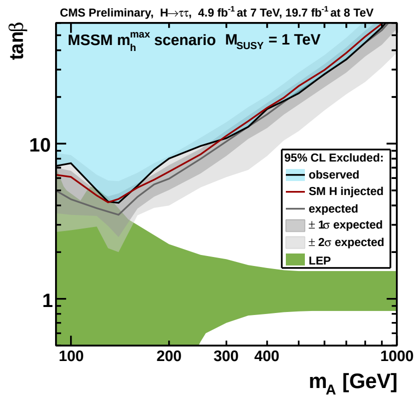

Figure 10: Region in m_A–$\tan\beta$ parameter space of the MSSM m_h^{max} scenario, excluded at 95% CL by the search for neutral MSSM Higgs bosons decaying to tau pairs. Expected limits have been computed for two cases: for the assumption that there is no Higgs $\to \tau\tau$ signal (neither MSSM nor SM) present in the data (dark grey line) and assuming that there is no MSSM, but a SM Higgs of mass ≈ 125 GeV present (red line).