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Neutral MSSM Higgs bosons from squark and gluino cascade decays with CMS

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On behalf of the CMS Collaboration

Abstract

In the framework of the Minimal Supersymmetric extension to the Standard Model, Higgs bosons can be produced, at LHC, from squark and gluino cascade decays. The discovery potential of heavy neutral Higgs bosons is investigated in four possible theoretical scenarios.

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1 Introduction

The Minimal Supersymmetric extention of the Standard Model (MSSM)[1] requires the existence of two Higgs field doublets which lead to five physical Higgs boson states: two CP-even states, h and H, a CP-odd state, A, and two charged states, $H^{\pm}$. At tree level, masses and couplings depend only on two parameters, $m_{\rm A}$ and tanβ. The masses of A, H and $H^{\pm}$ can in principle be arbitrarily large, while a stringent constraint, $m_{\rm h} < |\cos 2\beta| m_{\rm Z}$, forces h to be relatively light. When radiative corrections are included, the limit on the h mass can go up to $m_{\rm h} \lesssim 140$ GeV/c^2. The case of interest for the analysis presented here is $m_{\rm A} \sim m_{\rm h}{}^{\rm max}$, for which the masses of the three neutral Higgs bosons are comparable ($m_{\rm h} \sim m_{\rm A} \sim m_{\rm H}$) and still relatively small (about 130 to 150 GeV/c^2) (Fig. 1).

The Higgs boson couplings to fermions are proportional to the fermion mass. The associated production off top or bottom quarks is therefore preferred; on the other hand, the coupling to b quarks is enhanced by tanβ, which explains why the strategy normally adopted in searching for A and H exploits the study of Higgs boson production channels such as gg→ $\rm b\bar{b}$H/A.

The most favourable A/H decay channels studied are A/H→ $\tau^+\tau^-$ and A/H→ $\mu^+\mu^-$. The former has a sizeable branching ratio (∼10%). It is experimentally well accessible since all τ decay modes can be reconstructed, and is relatively easy to trigger on, since lepton and jet triggers can be used. The latter has a tiny branching ratio, of about 10^{-4}; the experimental signature, however, is extremely clean and both the muon trigger and reconstruction are highly efficient.

The studies performed so far in CMS with the channels mentioned above, however, cannot cover the region in the ($m_{\rm A}$,tanβ) plane with 130 $\lesssim m_{\rm A} \lesssim 150$ GeV/c^2 and tan$\beta \sim 5$, because the cross section of the A/H production channel drops

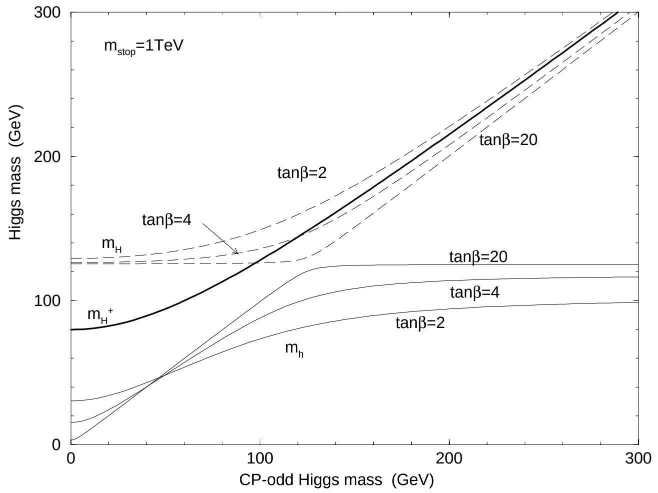

Fig. 1. Masses of the five physical Higgs bosons as a function of the CP-odd Higgs mass for various values of $\tan\beta$ [2].

quickly with $\tan^2\beta$. The lightest scalar Higgs boson h, though, can always be searched for in the whole (m_{A},$\tan\beta$) plane.

Another potential source of Higgs bosons in the MSSM is provided by gluino and squark cascade decays. Squarks and gluinos are strongly interacting sparticles and their production cross section in hadronic collisions is large, of the order of tens of pb for sparticle masses $m_{\tilde{\mathrm{g}}} \sim m_{\tilde{\mathrm{q}}} \sim 0.5$ to 1 TeV/c^2. Squarks and gluinos could then decay into heavy charginos, $\chi_2^{\pm}$, and neutralinos $\chi_{3,4}^0$ if enough phase space is available. These gauginos could decay into the lighter charginos, $\chi_1^{\pm}$, and neutralinos, $\chi_{1,2}^0$, plus a Higgs boson. In the rest of this report the discussion focuses on the neutral Higgs bosons of the MSSM. Squarks and gluinos might produce neutral Higgs bosons by decaying through "long cascade" decays (1)

$$\begin{aligned} \mathrm{pp} \rightarrow \tilde{\mathrm{g}}\tilde{\mathrm{g}}, \tilde{\mathrm{q}}\tilde{\mathrm{q}}, \tilde{\mathrm{q}}\tilde{\mathrm{q}}^*, \tilde{\mathrm{q}}\tilde{\mathrm{g}} &\rightarrow \chi_3^0, \chi_4^0 + \mathrm{X} \\ &\rightarrow \chi_2^0, \chi_1^0 + \mathrm{h/A/H} + \mathrm{X}, \end{aligned} \tag{1}$$

or by decaying directly to the next-to-lightest neutralino χ_2^0 via a "short cascade" (2).

$$\begin{aligned} \mathrm{pp} \rightarrow \tilde{\mathrm{g}}\tilde{\mathrm{g}}, \tilde{\mathrm{q}}\tilde{\mathrm{q}}, \tilde{\mathrm{q}}\tilde{\mathrm{q}}^*, \tilde{\mathrm{q}}\tilde{\mathrm{g}} &\rightarrow \chi_2^0 + \mathrm{X} \\ &\rightarrow \chi_1^0 + \mathrm{h/A/H} + \mathrm{X} \end{aligned} \tag{2}$$

Both cascades were studied for A/H masses of about 150 GeV/c^2 and for moderate to large Yukawa couplings to b quarks. The analysis is fully described in Ref. [3].

2 Squark and gluino cascade decays

2.1 The theoretical framework

The theoretical framework assumed for this analysis is a partially constrained MSSM model in which a sub-set of the assumptions normally made in the mSUGRA Model [1] are considered. While keeping the number of MSSM free parameters at a reasonable level so as to maintain some predictive power the phenomenological implications arising from looser theoretical constraints can be studied. In the constrained MSSM version used here chargino and neutralino masses are determined by the Higgsino mass parameter μ and the soft-SUSY breaking gaugino masses M_1 (bino mass), M_2 (wino mass) and M_3 (gluino mass). Gaugino mass unification at high-energy scale is assumed. At low-energy scale, the Renormalization Group Equations lead to $m_{\tilde{\mathrm{g}}} \sim M_3 \sim 2M_2 \sim 3M_1$. The sfermion masses unification at high-energy scale is also assumed. No assumptions are made concerning the Supersymmetry breaking mechanism.

2.2 Search scenarios

Four representative scenarios were chosen for this analysis, with different assumptions on the squark and gluino masses initiating the cascade decays. The choices of the parameters used in the analysis are as follows.

- Sc1: $M_2 = 2M_1 = 200\,\mathrm{GeV}/c^2$, $\mu = 300\,\mathrm{GeV}/c^2$, $m_{\tilde{\mathrm{g}}} = 600\,\mathrm{GeV}/c^2$ and $m_{\tilde{\mathrm{q}}} = 720\,\mathrm{GeV}/c^2$
- Sc2: $M_2 = 2M_1 = 300\,\mathrm{GeV}/c^2$, $\mu = 450\,\mathrm{GeV}/c^2$, $m_{\tilde{\mathrm{g}}} = 900\,\mathrm{GeV}/c^2$ and $m_{\tilde{\mathrm{q}}} = 1080\,\mathrm{GeV}/c^2$
- Sc3: $M_2 = 2M_1 = 350\,\mathrm{GeV}/c^2$, $\mu = 150\,\mathrm{GeV}/c^2$, $m_{\tilde{\mathrm{g}}} = 1200\,\mathrm{GeV}/c^2$ and $m_{\tilde{\mathrm{q}}} = 800\,\mathrm{GeV}/c^2$
- Sc4: $M_2 = 2M_1 = 350\,\mathrm{GeV}/c^2$, $\mu = 1000\,\mathrm{GeV}/c^2$, $m_{\tilde{\mathrm{g}}} = 1200\,\mathrm{GeV}/c^2$ and $m_{\tilde{\mathrm{q}}} = 800\,\mathrm{GeV}/c^2$

A common slepton mass was fixed to $m_{\tilde{\ell}}$= 500 GeV/c^2. A qualitative description is given below of the phenomenology expected in the four Scenarios which helps understanding the processes at play. In the first two Scenarios, squarks are assumed to be heavier than gluinos. They therefore decay predominantly to quark-gluino pairs, $\tilde{\mathrm{q}} \to \mathrm{q}\tilde{\mathrm{g}}$. Gluinos, either produced directly or from squark decays, would mainly decay into the heavier neutralino and chargino states initiating the cascade. If the mass splitting between the heavier neutralinos and the next-to-ligthest state is large enough, neutral Higgs bosons can be produced in the "long cascade". By fixing the gluino mass, M_2 is fixed, but μ is left free to vary.

Similar arguments are valid also for the second Scenario except that it differs from the first one because of the heavier gluino. With the gluino mass value chosen and for large enough μ, the lighter neutralinos are gaugino-like and $m_{\chi_2^0} \sim 2m_{\chi_1^0} \sim M_2$. The mass splitting between the lightest neutralino states is large enough for h with mass of ∼130 GeV/c^2 to be produced. As a result, neutral Higgs bosons can be produced through both the short and the long cascades in Scenario 2.

The third and fourth Scenarios are quite diverse; the most important difference is that gluinos are assumed to be heavier than squarks so that the decay $\tilde{g} \to \tilde{q}q$ has 100% branching fraction. Also, M_2 can vary, while μ is fixed to a small value (150 GeV/c^2) in Scenario 3 and large value (1000 GeV/c^2) in Scenario 4. In Scenario 3 all squarks decay mainly into the heavier gaugino-like neutralinos ($m_{\chi_4^0} \sim 2m_{\chi_3^0} \sim M_2$). For M_2 large enough, phase space is available for χ_4^0, χ_3^0 to decay in the lighter states allowing for production of Higgs bosons with masses smaller than 200 GeV/c^2 through the long cascade decay.

Finally in Scenario 4, only the Higgs boson production via the short cascade is open; the very large μ value makes the lighter neutralinos, χ_2^0, χ_1^0 gaugino-like. Squarks and gluinos can then decay into these states and if M_2 is large enough, χ_2^0 can decay into the LSP plus a Higgs boson.

The total production rates for at least one neutral or charged MSSM Higgs boson in either cascade or in both are shown in Fig. 2, as calculated using the HDECAY 2.0 program [4].

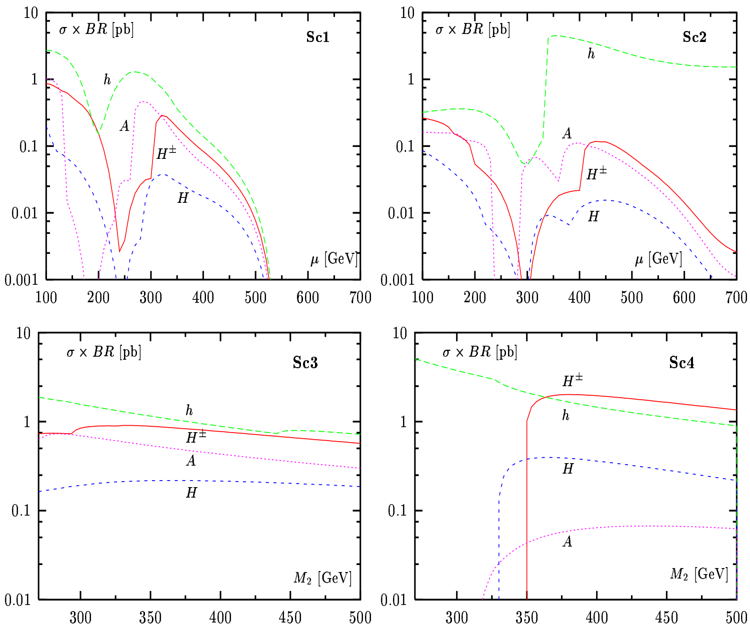

Fig. 2. Total production rates for MSSM Higgs bosons in the four Scenarios studied in this analysis; for Scenarios 1 and 2 they are shown as function of the Higgsino mass parameter while for Scenario 3 and 4 they are shown as a function of M_2. All values were calculated for m_A=150 GeV/c^2 and tanβ=5.

It was verified that the production rate depends only mildy on tanβ which is a major asset of this production mechanism, in contrast to the strong tanβ dependence of the direct A/H production.

2.3 Simulation tools

The SUSY sparticle mass spectrum was calculated with ISASUSY 7.58 [5]. Signal events and background were generated with HERWIG 6.4 [6]. The CMS detector effects were described with a fast simulation (CMSJET 4.8 [7]) in which a parametrized response of the detector is implemented.

2.4 Analysis strategy in a nutshell and results

The h/H/A decay channel to $b\overline{b}$ was considered. Event selection criteria were devised to aim at preserving high efficiency at the CMS High Level Trigger (HLT) [8] and at keeping the background from Standard Model processes (such as $t\overline{t}$ events) at a negligible level. These two requirements are actually correlated since the HLT conditions were designed to maximize the rejection of Standard Model jet background, exploiting large thresholds on jet energy and missing transverse energy. As shown, for instance, in Fig. 3, events originating from squark and gluino decays have much larger missing transverse energy and a cut at high value is very effective against the $t\overline{t}$ background. The assumption is made that the same cuts would have large rejection power against the QCD background, which is hence neglected here. The validity of the assumption, however, still needs to be carefully checked in a future update of the analysis.

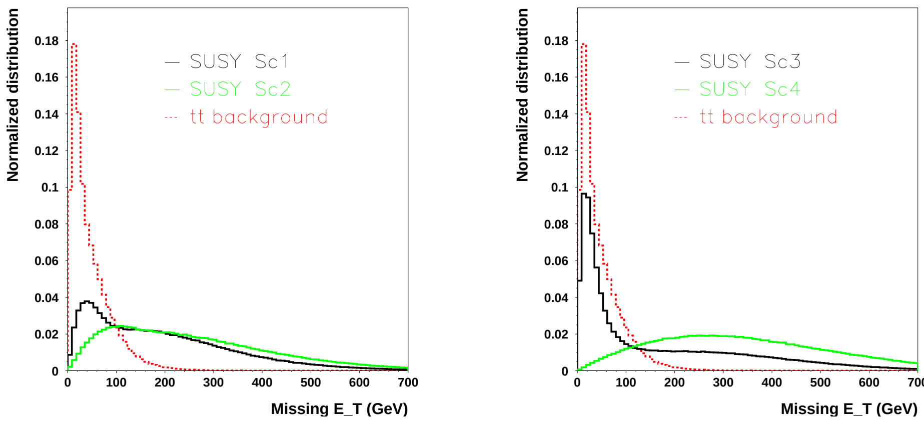

Fig. 3. Normalized distribution of the missing trasverse energy in SUSY cascades (continous lines) and Standard Model $t\overline{t}$ events (dahsed line) for the four different Scenarios.

Other kinematic variables were also considered in the event selection, such as the jet multiplicity in the event, the highest jet energy and the effective mass of the event. They all show good rejection power against the Standard Model background. No attempt was made to reduce the background arising from other Supersymmetric cascade processes, in order to avoid biases to the signal.

The selection finally applied consists of the following requirements: a) presence of at least five jets in the event of which at least two tagged as b jets (impact-parameter-based tag) and with transverse energy consistent with the Higgs boson mass range under investigation ($45 < E_T < 120$ GeV); b) E_T (most energetic jet) > 300 GeV; c) transverse missing energy $E_T^{\rm miss} > 150$ GeV and d) total energy $>$ 1200 GeV.

After the event selection, the pair of b jets closest in the (η, ϕ) space are used to estimate the Higgs boson invariant mass, looking for possible peaks corresponding to the Higgs generated masses $m_{\rm h}$= 110 GeV/c^2, $m_{\rm A}$= 150 GeV/c^2 and $m_{\rm H}$=160 GeV/c^2. The resulting invariant mass distributions are shown in Fig.4 for the four Scenarios under study.

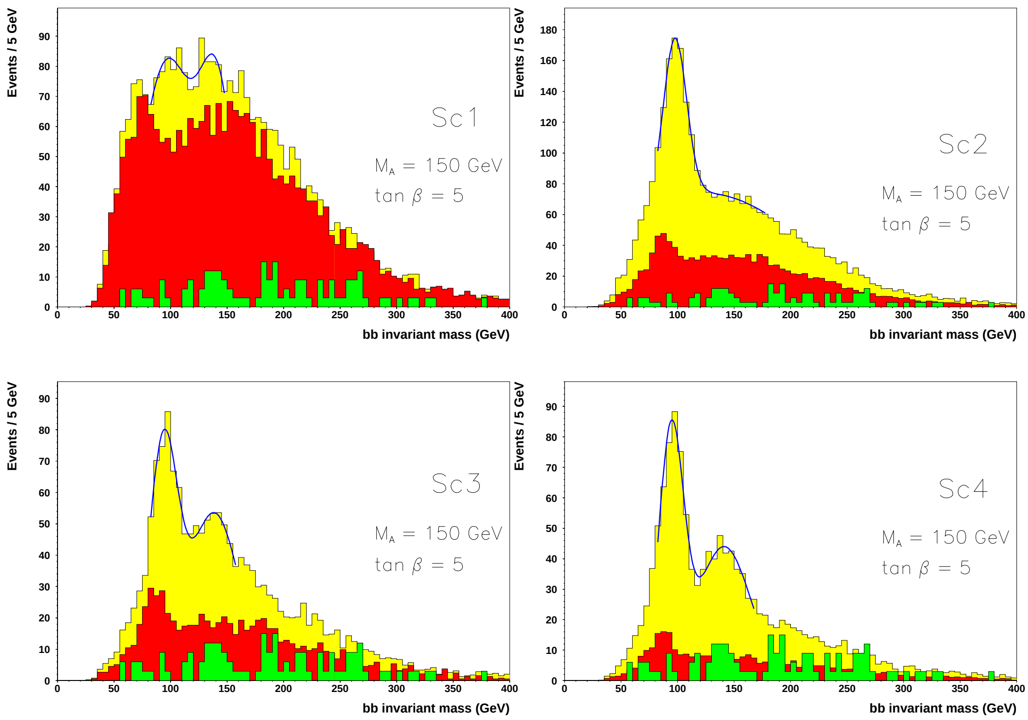

Fig. 4. Distribution of the $b\overline{b}$ invariant mass in the four Scenarios and for 30 fb^{-1}. The light-grey histograms show the signal plus background invariant mass distribution. The darker-grey histograms show the contributions from the SUSY cascade background processes and from the Standard Model $t\overline{t}$ events respectively.

The total (signal plus background) distribution is shown, together with the contributions from the SUSY cascades and Standard Model backgrounds. The SUSY background was generated including all processes leading to cascade decays while vetoing any Higgs boson production.

In Scenario 1 there is almost no evidence of signal accountable to Higgs boson production. In Scenario 2, the peak due to the h produced in the short cascade is large; A/H show only a broad shoulder at larger mass values. The signal to noise ratio extracted from them is, hence, not significative. The two Scenarios would require deeper study and understanding of the background.

In Scenario 3 and 4, in which the squarks are assumed to be lighter than gluinos, the visibility of the neutral Higgs boson is strongly enhanced. In the last Scenario h and A/H would all be produced in the short cascade decay.

3 Conclusions

Chances of detecting heavy neutral Higgs bosons from the MSSM, originating from squark and gluino cascade decays, were investigated. Although the variety of conditions, depending on the values of the MSSM parameters, is wide, four different representative Scenarios were studied, hopefully covering most of the situations which might occur if Nature chose to be described by the MSSM, with squarks either lighter or heavier than the gluinos and the light neutralinos (charginos) either gaugino- or higgsino-like.

Although the analysis is not pushed in its deepest details, it leads to promising expectations, especially if squarks are lighter than gluinos. In such a case, the total production rate of heavy neutral Higgs bosons from squark and gluino cascade decays would be large and almost independent from tanβ. The heavier A/H could be searched for up to masses of about 220 GeV/c^2 covering also the region of the ($m_{\rm A}$,tanβ) plane left uncovered by the "conventional" Higgs boson search techniques as shown in Fig. 5.

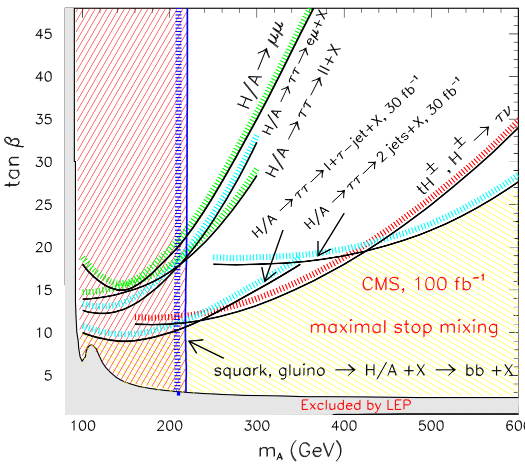

Fig. 5. The coverage of the ($m_{\rm A}$,tanβ) plane is shown for the A and H "standard" search channels at CMS as well as for the searches through the squark and gluino "long cascade" decays resulting from Scenario 3. The contours shown here are obtained for 100 fb^{-1}. A similar contour is obtained for "short cascades" in Scenario 4. The hatched bottom-right corner of the plane shows the region where only the scalar h can be found.

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