MSSM HIGGS BOSON PRODUCTION FROM
SUPERSYMMETRIC CASCADES AT LHC *

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Detectability of MSSM Higgs bosons in cascade decays of supersymmetric particles at the CERN LHC is discussed.

1. Introduction

The Minimal Supersymmetric Standard Model (MSSM) have got 5 physical Higgs scalars: 2 neutral CP-even, \( h \) (the lightest one) and \( H \); 1 neutral CP-odd, \( A \); and 2 charged ones, \( H^\pm \). The search strategies for these Higgs bosons have thus far been based mainly on their direct productions through Standard Model (SM)–like processes \( \text{viz.}, gg \to h, A, gg/q\bar{q} \to h, H, A + b\bar{b}/t\bar{t} \) for the neutral Higgses and \( t \to H^+ b, gg/q\bar{q} \to H^+ b\bar{t} \) and \( gb \to H^- t \) for the charged Higgs (see Ref. 1,2 and references therein). Rates of most of these processes are strongly enhanced as \( \tan \beta \) grows. In this talk I briefly explore another potential source of MSSM Higgs bosons at the CERN Large Hadron Collider (LHC) in cascade decays of squarks and gluinos.

2. The scheme

If kinematically allowed, squarks and gluinos, copiously produced at LHC, could undergo the following cascade patterns in their decay:

\[
pp \to \tilde{g}\tilde{g}, \tilde{q}\tilde{q}, \tilde{q}\tilde{g}, \tilde{g}\tilde{g} \to \chi_2^\pm, \chi_3^0, \chi_4^0 + X \to \chi_1^\pm, \chi_2^0, \chi_3^0 + h, H, A + X \quad (1)
\]

\[
pp \to \tilde{g}\tilde{g}, \tilde{q}\tilde{q}, \tilde{q}\tilde{g} \to \chi_1^\pm, \chi_2^0 + X \to \chi_3^0 + H^\pm, h, H, A + X \quad (2)
\]

We call the decay chain in eq. (1) the “big cascade” while the one in eq. (2) is dubbed the “little cascade”. Other possibilities include:

\[
pp \to \tilde{t}_2^\pm, \tilde{b}_2^\pm \text{ with } \tilde{t}_2(\tilde{b}_2) \to \tilde{t}_1(\tilde{b}_1) + h/H/A \text{ or } \tilde{b}_1(\tilde{t}_1) + H^\pm \quad (3)
\]

\[
pp \to \tilde{g}\tilde{g}, \tilde{q}\tilde{q}, \tilde{q}\tilde{g} \to t\bar{t} + X \to H^\pm + X \quad (4)
\]

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Little cascades were discussed earlier \(^3,4\) for \(h\) and relatively light \(A, H\) and \(H^\pm\). We reanalyze this case in a broader perspective along with the newly proposed big cascades \(^5\). Fast simulations for the signal and the backgrounds are performed including CMS detector response at the LHC.

3. The motivation

The motivating factors are: (i) couplings involved in cascades are ingredients of weak scale SUSY Lagrangian and would bear informations on the electroweak symmetry breaking sector; (ii) existence of a hole (where only the lightest \(h\) boson can be found at the LHC) in the canonical reach plot spanning over \(130 \lesssim M_A \lesssim 170\) GeV and \(\tan \beta \sim 5\) is traced back to insufficient production rates at lower \(\tan \beta\). With SUSY cascades as the dominant source of Higgses, \(\tan \beta\) dependence gets diluted. This could fill up the hole; (iii) SUSY cascades are sources of MSSM Higgs bosons of much unforeseen potential and hence, on its own right, must be analyzed anyway.

4. Analysis and Observations

We recently made \(^5\) a detailed analysis over the allowed parameter space. However, in this talk I only discuss to what extent can one fill up the above-mentioned hole and the possible reach for different Higgses thereon.

We make no assumptions to relate the two Higgs mass parameters, \(m_{H_1}\) and \(m_{H_2}\), and the masses of squarks and/or sleptons. However, gaugino mass unification at a high scale is assumed. A somewhat large value of the trilinear \(A\) parameter \((A_t=A_B=1.5\) TeV\) helps evade the LEP bound on \(m_h\) and leads to the typical mixing scenario. The Higgs sector is treated with \texttt{HDECAY} and \texttt{CTEQ3L} \(^6\) parton distributions are used. To be conservative, \(K\)-factors and QCD corrections to squark/gluino decays are not considered.

The study exploits the large rates for squarks and gluinos at LHC. This is a prerequisite for healthy Higgs rates under cascades which typically involve an effective branching ratio of only a few percent for \textit{single} Higgs final states. Typical total rate for squarks and gluinos is \(\sim 110(3)\) pb for \(m_{\tilde{q}} \sim m_{\tilde{g}} \sim 0.5(1)\) TeV. This leads to a large \((\sim 10^6(10^5))\) number of parent events for the cascades with an accumulated luminosity \((\int L) \sim 30\) fb\(^{-1}\).

A key point here is that the couplings of the Higgs bosons to charginos and neutralinos are maximal for higgsino-gaugino mixed states \(^7\). This results in dominant decays of the heavier chargino and neutralinos into the lighter ones and Higgs bosons. A similar argument holds for the little cascades in the gaugino region whenever kinematically allowed.
For illustration I consider a generic scenario with $m_{\tilde{g}} (= 3M_2) > m_{\tilde{q}} (= 800 \text{ GeV})$. Hence, $Br[\tilde{g} \rightarrow \tilde{q}\tilde{q}] = 100\%$. Effectively, then, all electroweak cascades start with the squarks. Setting the higgsino mass parameter $\mu = 150 \text{ GeV}$ makes the lighter “ino”s higgsino-like and degenerate thus closing the little cascades. Also, squarks of lighter families mainly decay to gaugino-like heavier chargino and neutralinos which undergo big cascades to produce Higgs bosons. We try to probe the lacuna in the $M_A - \tan \beta$ space and so set $M_A = 150 \text{ GeV}$ and $\tan \beta = 5$. This results in $M_h \simeq 110 \text{ GeV}$ (still not SM-like; hence LEP bound does not apply) and $M_{H^\pm} \simeq 170 \text{ GeV}$.

The figure on above left shows that rates for different MSSM Higgses lie between $0.1–1 \text{ pb}$ for a range of $M_2$. Thus a large number of Higgs events (up to $\sim 10^4$ with $\int \mathcal{L} = 30 \text{ fb}^{-1}$) is expected in few years of LHC run.

Fast Monte Carlo simulation involves MSSM spectrum from ISASUSY v7.58 interfaced to HERWIG 6.4 by ISAWIG to generate the signal and the backgrounds while detector response is included through CMSJET 4.801.

Large SUSY background comes from SUSY events not containing the Higgs bosons. Comparatively smaller SM one comes from the $t\bar{t}$ process. Basic kinematic distributions studied are the jet multiplicities, $p_T$ and $E_T^{jet}$.

We then analyze the $b\bar{b}$ decay mode ($BR \sim 90\%$) for the neutral Higgses. Suitable lower cuts are employed for all of the above variables. These help distinguish the reconstructed peaks for $h$ and $A, H$ in the $b\bar{b}$ mass spectrum. For $H^\pm$ we choose the decay mode $H^\pm \rightarrow \tau^\pm \nu_{\tau}$ ($BR \sim 95\%$). We use similar cuts but presence of neutrinos prohibits reconstruction of the mass peak. Hence, we further exploit the tau-polarization features with TAUOLA 8 to tame the dominant SM background from $W^\pm \rightarrow \tau^\pm \nu_{\tau}$. Even then, the evidence for $H^\pm$ is not as compelling as for neutral Higgses. However, this when combined with prior observation of neutral Higgses could bring forth a solid circumstantial evidence for $H^\pm$.

The figure on right summarizes reach for $\int \mathcal{L} = 100 \text{ fb}^{-1}$ with $M_2=350 \text{ GeV}$ in this scenario. In the hatched vertical column on left, heavier CP-even $H$ and pseudoscalar $A$ can be observed in the (big) cascades for $M_A \lesssim$
220 GeV for all \( \tan \beta \). The corresponding reach in \( M_{\tilde{H}} \) is \( \sim 200 \) GeV. We see that this fills up the hole in the low \( m_A \) and intermediate \( \tan \beta \) region and thus becomes complementary to the standard searches.

Of course, there are generic scenarios where both little and big cascades may be present simultaneously \(^5\) which could enhance the signal. We find, under favorable situation, one or more Higgs bosons with \( M_\phi \lesssim 200 \) GeV can be probed in SUSY cascades even with \( \int L = 30 \text{ fb}^{-1} \). Here, I do not discuss the cascades in eqs. (3) and (4) which would further enhance the yield of MSSM Higgses. Also, a better understanding of the SUSY backgrounds would help improve the overall reach.

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