Observability of MSSM Higgs bosons decaying to sparticles at the LHC

Filip Moortgat
Department of Physics, University of Antwerpen,
Universiteitsplein 1, B-2610 Wilrijk, Belgium

The possibility is discussed to observe the sparticle decay modes of the heavy MSSM Higgs bosons at the Large Hadron Collider. We focus on the heavy neutral Higgses H^0 and A^0, and argue that their decay into neutralinos may access an interesting region in MSSM parameter space up to m_A = 450 GeV for low and intermediate values of $\tan\beta$. If neutralinos and sleptons are light enough, the H^0, $A^0 \rightarrow \chi_2^0\chi_2^0 \rightarrow 4l^\pm + X$ channel can complement the reach of the SM channels.

1 Introduction

In order to explain the mechanism of electroweak symmetry breaking in the Minimal Supersymmetric Standard Model (MSSM), the existence of two Higgs doublets is assumed, leading to five physical Higgs bosons: a light CP-even (h^0), a heavy CP-even (H^0), a heavy CP-odd (A^0) and two charged Higgs bosons ($H^\pm$). A discovery of one of these heavy Higgses would therefore be a major breakthrough in verifying the supersymmetric nature of the underlying theory. At the Large Hadron Collider (LHC), the most promising channels to discover the heavy Higgs bosons seem to be the $H^0, A^0 \longrightarrow \tau\tau$ or the $H^+ \longrightarrow \tau\nu$ channel. These channels[1] were studied extensively in the CMS and ATLAS Collaborations and can lead to discoveries in the large and intermediate $\tan\beta$ region of the MSSM parameter space. In the studies of these channels, it was assumed that sparticles are heavy ($\sim$ 1 TeV), and do not participate in the decay process. However, if neutralinos and/or charginos would be light, the branching ratios into these sparticles will be sizable. Therefore we investigate whether there is a way to observe such $H^0, A^0 \longrightarrow \chi^+\chi^-, \chi^0\chi^0$ decays. We will show that in the low and intermediate $\tan\beta$ region of the MSSM parameter space, this might indeed be the case for $250 \lesssim m_A \lesssim 450$ GeV, depending on the values of M_2, μ and $m_{\tilde{l}}$.

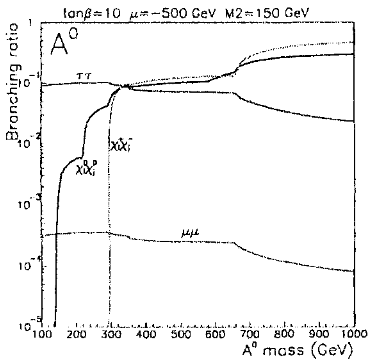

Figure 1: Example of the branching ratios of A^0 into $\tau\tau$, $\mu\mu$ and sparticles.

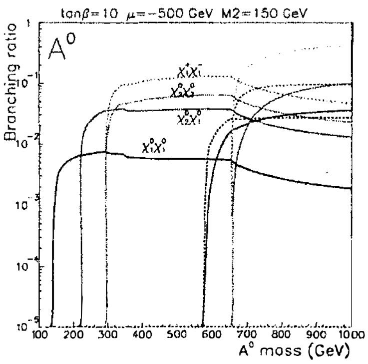

Figure 2: Detailed branching ratios of A^0 into neturalinos and charginos.

2 Neutralino/chargino decay modes at the LHC

2.1 Branching ratios

The supersymmetric decay modes of the heavy Higgses were first studied in the MSSM framework using the HDECAY[2] package. Fig. 1 shows the branching ratios of A^0 into the $\tau\tau$, the $\mu\mu$ and the sparticle modes, for the chosen set of MSSM parameters. For $m_A \lesssim$ 500 GeV, the decay probability of the heavy Higgs into neutralinos and charginos can be as high as 20%. The other sparticle decay modes seem to be neglegible. Looking more in detail to the chargino/neutralino modes (fig. 2), one sees that the $\chi_1^+\chi_1^-$ decay mode gives the highest branching ratio (for $m_A \lesssim$ 500 GeV), while the second best sparticle mode is $\chi_2^0\chi_2^0$. In view of the large backgrounds at the LHC, the leptonic decay modes of the neutralinos/charginos seem most preferable: $\chi_2^0 \to l^+l^-\chi_1^0$ and $\chi_1^\pm \to l^\pm\nu\chi_1^0$. The amplitude of the $\chi_2^0 \to l^+l^-\chi_1^0$ decay strongly depends on the values of M_1, M_2, $\tan\beta$, μ and $m_{\tilde{l}}$. This is due to the fact that for the decay to leptons, two diagrams contribute: the Z^0 exchange and the virtual slepton exchange. Depending on the value of μ, it may be more favourable to have light or heavy sleptons, because the diagrams can interfere positively as well as negatively. However, in general the branching ratio into electrons and muons will decrease with $\tan\beta$ due to the enhanced coupling with taus.

In order to have a strong experimental signature allowing to suppress the backgrounds, we will consider the channel

$$A^0, H^0 \to \chi_2^0\chi_2^0 \to 4l^\pm + X \tag{1}$$

with four *isolated* leptons (e, μ) in the final state.

The $A^0, H^0 \to \chi_2^0\chi_2^0 \to 4l^\pm$ cross section was first scanned in the m_A - $\tan\beta$ plane for different values of M_2, μ and $m_{\tilde{l}}$. In figs. 3 and 4, the plot of $\sigma\times$ BR for M_1 = 60 GeV, M_2 = 110 GeV, μ = -500 GeV and $m_{\tilde{l}}$ = 250 GeV is shown for the H^0 and A^0. Values of $\tan\beta \lesssim$ 30 and $m_A \lesssim$ 400 GeV are favoured. One also notices that the pseudoscalar Higgs gives much higher cross sections than the scalar one, due to its stronger coupling to $b\bar{b}$ (for $\tan\beta \gtrsim$ 5, the associated production mechanism $gg, q\bar{q} \to A^0, H^0 b\bar{b}$ dominates over the gluon fusion $gg \to A^0, H^0$).

We will first choose a favourable point in parameter space and study whether we can observe this $4l^\pm$ signal above the expected backgrounds.

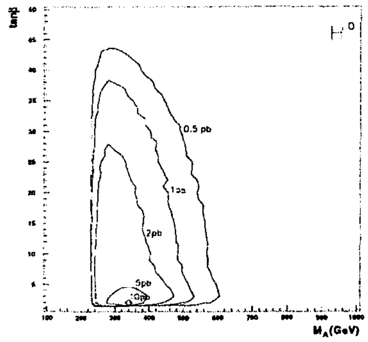

Figure 3: $\sigma\times$ BR contours for H^0 in the $m_A - \tan\beta$ plane. MSSM parameter values as described in the text.

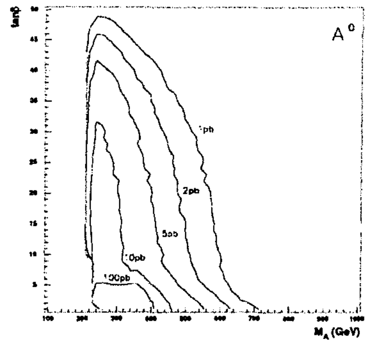

Figure 4: $\sigma\times$ BR contours for A^0 in the $m_A - \tan\beta$ plane. MSSM parameter values as described in the text.

2.2 Event generation

The signal $A^0, H^0 \longrightarrow \chi_2^0\chi_2^0 \dashrightarrow 4l^{\pm}$ was generated with SPYTHIA [3]. The signature contains two pairs of leptons with opposite sign and same flavour, in addition to a substantial amount of missing energy due to the escaping lightest neutralinos.
Possible backgrounds that can mimick this signature are ZZ, ZW, $Zb\bar{b}$, $Zc\bar{c}$, $Wt\bar{b}$ and $t\bar{t}$ final states in the Standard Model and $\tilde{q}/\tilde{g}$, $\tilde{l}\tilde{l}$, $\tilde{\nu}\tilde{\nu}$, $\tilde{q}\tilde{\chi}$, $\tilde{\chi}\tilde{\chi}$ production in the MSSM extension.
The background events are generated with PYTHIA 6.136 [4]. The CMS detector response was simulated using the fast simulation package CMSJET [5].

2.3 Event selection

We can first discriminate between the signal and the background by making the following basic requirements:

- there must be four *isolated* leptons (e/μ) in the final state, with a transverse momentum higher than 10 GeV and with $\eta < 2.4$. We demand a tight isolation of the leptons in the tracker (no charged particle with $P_T > 1.5$ GeV in the cone of 0.3 rad around each lepton track) as well as in the electromagnetic calorimeter (the sum of the transverse energy in the crystal towers between 0.05 and 0.3 rad around the track has to be smaller than 3 GeV)

- we only consider lepton pairs with dilepton effective mass outside the range $m_Z\pm$ 10 GeV (Z veto).

These conditions effectively suppress the SM backround processes. The explicit Z veto is used in order to maximally suppress the ZZ and WZ backgrounds, while the $t\bar{t}$ background practically disappears if the lepton isolation criterion is tight enough.
Further optimisation of the signal to background ratio can be obtained by requiring that:

- P_T hardest lepton $<$ 80 GeV
- 20 Gev $< E_T^{miss} <$ 130 GeV
- E_T hardest jet $<$ 100 GeV

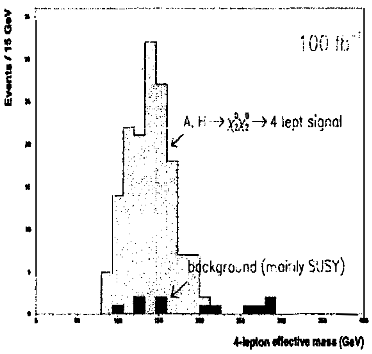

Figure 5: Signal over background for *case 1* in the 4-lepton effective mass plot. MSSM parameters as described in the text.

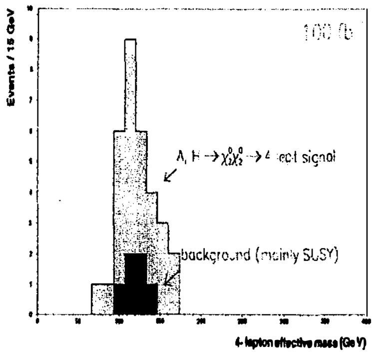

Figure 6: Signal over background for *case 2* in the 4-lepton effective mass plot. MSSM parameters as described in the text.

- if necessary (light squark/gluino): only 0,1,2 jets

The only important SM background process still surviving these requirements is ZZ production, mainly when one of the Z bosons decays into taus. Most of the background events surviving the selection are supersymmetric in nature: sneutrino and neutralino direct pair production.

2.4 Case studies

We focus on two points in the MSSM parameter space. The first one is the point where the signal cross section is optimal. In the second point, the case of heavier neutralinos and a positive value for μ is considered.

Case 1:

The following values for the MSSM parameters were chosen: M_2 = 120 GeV, M_1 = 60 GeV, μ = -500 GeV, $m_{\tilde{l}}$ = 250 GeV, $M_{\tilde{q},\tilde{g}}$ = 1000 GeV. In this case we can obtain a clear signal over the background, like in fig. 5 for m_A = 320 GeV and $\tan\beta = 5$ (best case).
In fig. 7, the region in the $m_A - \tan\beta$ plane is plotted where a 5σ-discovery could be made for an integrated luminosity of 30 and 100 fb^{-1}, provided we understand the nature of both SM and SUSY backgrounds in the final state topology. The discovery region starts where the $\chi_2^0\chi_2^0$ decay becomes kinematically accessible, $m_A \geq 2m_{\chi_2^0}$ = 225 GeV; the upper reach in m_A is mainly determined by the A/H production cross section, which drops with m_A as a power law. The reach in $\tan\beta$ is determined by the branching ratio of $\chi_2^0 \to l^+l^-\chi_1^0$. At 30 fb^{-1}, the discovery region reaches $m_A \sim$ 350 Gev and $\tan\beta \sim 20$. For 100 fb^{-1}, we see that values of $\tan\beta \sim 40$ and masses up to $m_A \sim$ 450 GeV are accessible. This area is - at least partly - covering the difficult region of MSSM parameter space that is not easily accessible for SM decays of SUSY Higgses - except for the $h \to b\bar{b}$ mode.

Case 2:

The following MSSM parameter choices were made: M_2 = 180 GeV, M_1 = 100 GeV, μ = +500 GeV, $m_{\tilde{l}}$ = 250 GeV, $M_{\tilde{q},\tilde{g}}$ = 1000 GeV. Here, the mass of the next-to-lighest neutralino will be larger, so the $\chi_2^0\chi_2^0$ mode will only start being accessible around $m_A \sim$ 350 GeV.

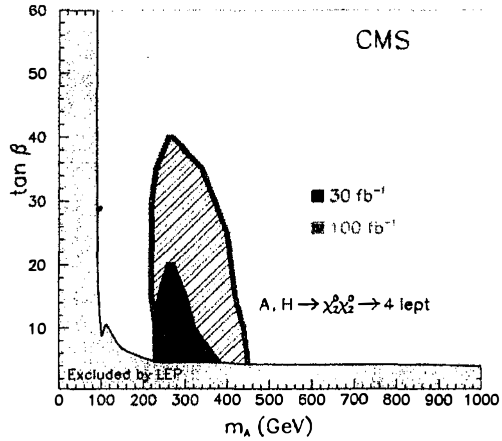

Figure 7: 5σ discovery contours for *case 1* at 30 and 100 fb^{-1}. MSSM parameters: M_2 = 120 GeV, M_1 = 60 GeV, μ = -500 GeV, $m_{\tilde{l}}$ = 250 GeV, $M_{\tilde{q},\tilde{g}}$ = 1000 GeV.

In fig. 6 the expectations are shown for m_A = 380 GeV and $\tan\beta = 10$. The excess of the signal over the background is less pronounced than in *case 1*, but still very clearly visible.

Due to the $\chi_2^0 \to l^+l^-\chi_1^0$ decay, there will be a clear "kinematical edge" at the mass difference M_2 - M_1 in the dilepton effective mass spectrum for the signal events. Even a double kinematic edge is visible in the di-electron versus the di-muon effective mass plot. Therefore, an observation of the signal would also allow us to determine extra parameters in the theory.

3 Conclusions and Outlook

The channel $H^0, A^0 \to \chi_2^0\chi_2^0 \to 4\,l^\pm$, with four isolated leptons in the final state, may be observed in the low and intermediate $\tan\beta$ region of the MSSM parameter space, if neutralinos and sleptons are light enough. This region is largely complementary to the reach of the H^0, $A^0 \to \tau\tau$ channel. The discovery potential will depend on other MSSM parameters like m_A, $\tan\beta$, M_1, M_2, μ and $m_{\tilde{l}}$. We are currently mapping the reach in m_A-$\tan\beta$ parameter space varying these parameters. As a next step, one might ask whether it would be possible to observe the supersymmetric decay of the charged Higgs $H^+ \to \chi_2^0\,\chi_{1,2}^\pm$ at the LHC. In order to suppress the background, a final state with three isolated leptons seems preferable. Since the charged Higgs is mainly produced via $gb \to tH^+$, we can also try to reconstruct the associated top quark for additional background suppression. Investigations of this topic are under way.

References

1. R. Kinnunen and D. Denegri, CMS Note 99-037; R. Kinnunen, CMS Note 2000-045.
2. A. Djouadi, J. Kalinowski and M. Spira, HDECAY, Comput. Phys. Comm. **108**,5 (1998).
3. S. Mrenna, SPYTHIA, A supersymmetric extention of PYTHIA, ANL-HEP-PR-96-63.
4. T. Sjostrand, Comp. Phys. Comm. **82**, 74 (1994).
5. S. Abdullin, A. Khanov and N. Stepanov, CMSJET, CMS Note 94-180; *http://cmsdoc.cern.ch/~abdullin/cmsjet.html*.