Invisible Decays of Supersymmetric Higgs Bosons

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Abstract. We study the detection of the complete spectrum of Higgs bosons of the minimal supersymmetric standard model, through their decays into chargino ($\widetilde{\chi}_i^{\pm}$) and neutralinos ($\widetilde{\chi}_i^o$), for several parametric scenarios. In the minimal supersymmetric model there are two charginos and four neutralinos, and the Higgs boson spectrum contains three neutral scalars, two CP-even (h^0 and H^0 with $m_{H^0} > m_{h^o}$) and one CP-odd (A^0, with m_{A^0} as a free parameter); as well as a charged pair ($H^{\pm}$). An interesting signal comes from the decays of the Higgs bosons into invisible SUSY modes (h^0, H^0,$A^0 \to \widetilde{\chi}_1^o \widetilde{\chi}_1^o$), which could be detected at present and future high energy machines.

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INTRODUCTION

In this work the detection of supersymmetric Higgs bosons is studied. It is known that the experimental techniques for the detection of Higgs bosons, through decays into Standard Model (SM) modes, are barely sufficient for possible detection in the current and future accelerators, but they could not conclude that the signals are truly supersymmetric particles [1]. So, to test the Higgs sector in SUSY it will be necessary to detect more than one Higgs, or any decay that is not present in the SM, as those of three bodies, or even decays into supersymmetric particles. Of these particles, the charginos and the neutralinos are the lightest expected. Moreover, if it happens that the lightest neutralino is stable, then the signal that would come from the decay would be a clear test of SUSY, as in that process the neutralinos would escape from the detectors of the accelerators, is known as invisible decay.

NEUTRALINOS AND CHARGINOS

In the minimal supersymmetric extension of the Glashow-Weinberg-Salam theory there are two charged gaugino states (charginos) $\widetilde{\chi}_i^{\pm}$ ($i = 1,2$), and four neutral gaugino states (neutralinos) $\widetilde{\chi}_i^o$ ($i = 1,...,4$). The carginos are mixtures of $\widetilde{W}^{\pm}$, $\widetilde{H}_1^+$ and $\widetilde{H}_2^-$, whereas the neutralinos are linear superpositions of $\widetilde{\gamma}$, $\widetilde{Z}$ and $\widetilde{H}_1^0$ and $\widetilde{H}_2^0$ [2]. Particularly, the Higgs boson can decay into neutralino and chargino pairs. Moreover, there are no constraints on the lightest neutralino, which we assume to be lightest supersymmetric particle.

COMPUTATION OF THE DECAY WIDTH

Process $H^0 \to \widetilde{\chi}_i^0 \widetilde{\chi}_j^0$

We now present formulae for computation of the partial decay width for charginos $\widetilde{\chi}_i^+$ and neutralinos $\widetilde{\chi}_i^0$. Initially we will begin to compute the decay process $H^0 \to \widetilde{\chi}_i^0 \widetilde{\chi}_j^0$, whose Feynman diagram is shown in Figure 1.

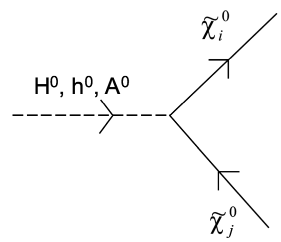

FIGURE 1. Feynman rules for the coupling of neutralinos to a neutral Higgs bosons (H^0, h^0 and A^0) in the MSSM.

The differential equation for one particle decaying into two particles is [3]:

$$d\Gamma = \frac{1}{32\pi^2} |\overline{\mathscr{M}}|^2 \frac{P_f}{M_{H^0}^2} d\Omega,$$

where

$$P_f = |\overrightarrow{P}_1| = |\overrightarrow{P}_2| = \frac{[(M_{H^0}^2 - (m_{\widetilde{\chi}_i^0} + m_{\widetilde{\chi}_j^0})^2)(M_{H^0}^2 - (m_{\widetilde{\chi}_i^0} - m_{\widetilde{\chi}_j^0})^2)]^{1/2}}{2M_{H^0}} \tag{1}$$

and $d\Omega = 2\pi \sin\theta d\theta$.

Therefore, performing the pertinent operations the final equation is

$$\Gamma(H^0 \to \widetilde{\chi}_i^0 \widetilde{\chi}_j^0) = \frac{1}{8\pi} \frac{P_f}{M_{H^0}^2} |\overline{\mathscr{M}}|^2. \tag{2}$$

The expression for the squared amplitude is

$$\begin{aligned} |\overline{\mathscr{M}}|^2 &= \mathsf{g}^2 \{ [M_{H^0}^2 - m_{\widetilde{\chi}_i^0}^2 - m_{\widetilde{\chi}_j^0}^2][\cos^2\alpha (Q_{ji}^{''*} Q_{ij}^{''} + Q_{ij}^{''} Q_{ji}^{''*}) + \sin^2\alpha (S_{ji}^{''*} S_{ij}^{''} + S_{ij}^{''} S_{ji}^{''*}) \\ &- \cos\alpha \sin\alpha (Q_{ji}^{''*} S_{ij}^{''} + S_{ji}^{''*} Q_{ij}^{''} + Q_{ij}^{''} S_{ji}^{''*} + S_{ij}^{''} Q_{ji}^{''*})] - [2 m_{\widetilde{\chi}_i^0} m_{\widetilde{\chi}_j^0}] \times \\ &[\cos^2\alpha [(Q_{ji}^{''*})^2 + (Q_{ij}^{''})^2] + \sin^2\alpha [(S_{ji}^{''*})^2 + (S_{ij}^{''})^2] - \cos\alpha \sin\alpha (Q_{ji}^{''*} S_{ji}^{''*} + \\ &S_{ji}^{''*} Q_{ji}^{''*} + Q_{ij}^{''} S_{ij}^{''} + S_{ij}^{''} Q_{ij}^{''})] \} \end{aligned}$$

and introducing the expression of $|\overline{\mathscr{M}}|^2$ into the equation (2), will obtain the kinematical factor

$$\lambda = (m^2_{\widetilde{\chi}^0_i} + m^2_{\widetilde{\chi}^0_j} - M^2_{H^0})^2 - 4m_{\widetilde{\chi}^0_i}{}^2\, m^2_{\widetilde{\chi}^0_j}. \tag{3}$$

In addition to the preceding factors, we will introduce the factor η_k. We assume that the factor η_K is equal to 1 for scalar Higgses (H^0, h^0), and is equal to -1 for the pseudoscalar Higgs (A^0). The factor $(1+\delta(i,j))$ is inserted to allow for the case in which two identical Majorana neutralinos appear in the final state. In this case, $\delta(i,j) = 1$, otherwise, it is equal to zero. Substituting the value of η_k, λ, $(1+\delta(i,j))$, $|\overline{\mathscr{M}}|^2$ and P_f into the equation (2), and carrying out the corresponding operations, we obtain:

$$\begin{aligned}\Gamma(H^0 \to \widetilde{\chi}^0_i \widetilde{\chi}^0_j) \;=\;& \frac{g^2 \lambda^{\frac{1}{2}}}{16\pi M^3_{H^0}(1+\delta(i,j))}\{[\cos^2\alpha[(Q''_{ij})^2 + (Q''_{ji})^2] \\ & -2\cos\alpha\sin\alpha(Q''_{ij}S''_{ij} \\ & +Q''_{ji}S''_{ji}) + \sin^2\alpha[(S''_{ij})^2 + (S''_{ji})^2]][M^2_{H^0} - m^2_{\widetilde{\chi}^0_i} - m^2_{\widetilde{\chi}^0_j}] \\ & -4m_{\widetilde{\chi}^0_i} m_{\widetilde{\chi}^0_j}[\cos^2\alpha(Q''_{ij})(Q''_{ji}) - \cos\alpha\sin\alpha(Q''_{ij}S''_{ji} + S''_{ij}Q''_{ji}) \\ & +\sin^2\alpha(S''_{ij})(S''_{ji})]\}.\end{aligned} \tag{4}$$

Writing the factors

$$F_{ijH^0} = \frac{1}{\varepsilon_i}[\cos\alpha Q''_{ij} - \sin\alpha S''_{ij}], \tag{5}$$

$$F_{jiH^0} = \frac{1}{\varepsilon_j}[\cos\alpha Q''_{ji} - \sin\alpha S''_{ji}], \tag{6}$$

where ε_i, ε_j to be either positive or negative, we will obtain an equation equivalent to the equation (4).

Substituting the equations (5) and (6) in the equation (4) we find the following expression:

$$\begin{aligned}\Gamma(H^0 \to \widetilde{\chi}^0_i \widetilde{\chi}^0_j) \;=\;& \frac{g^2 \lambda^{\frac{1}{2}}}{16\pi M^3_{H^0}(1+\delta(i,j))} \\ & \times \left((F^2_{ijH^0} + F^2_{jiH^0})(M^2_{H^0} - m^2_{\widetilde{\chi}^0_i} - m^2_{\widetilde{\chi}^0_j}) - 4F_{ijH^0}F_{jiH^0}\varepsilon_i\varepsilon_j\eta_{H^0} m_{\widetilde{\chi}^0_i} m_{\widetilde{\chi}^0_i} \right).\end{aligned} \tag{7}$$

In this way the equation for the decay width for the process $H^0 \to \widetilde{\chi}^0_i \widetilde{\chi}^0_j$ is obtained. A similar procedure to the previous one, is used for the computation of the decays widths of $h^0 \to \widetilde{\chi}^0_i \widetilde{\chi}^0_j$ and $A^0 \to \widetilde{\chi}^0_i \widetilde{\chi}^0_j$ processes.

Process $H^0 \to \widetilde{\chi}^+_i \widetilde{\chi}^+_j$

Immediately we will do the computation for the decay width of the process $H^0 \to \widetilde{\chi}^+_i \widetilde{\chi}^+_j$, using a procedure analogous to that used in the previous process.

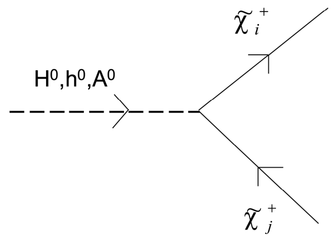

FIGURE 2. Feynman rules for the coupling of charginos to a neutral Higgs bosons in the MSSM.

Again, we will do use of equation (2) to calculate the decay width of the present process.

The expression for the square amplitude is

$$\begin{aligned}|\overline{\mathscr{M}}|^2 &= \mathsf{g}^2\{[M_{H^0}^2 - m_{\widetilde{\chi}_i^+}^2 - m_{\widetilde{\chi}_j^+}^2][\cos^2\alpha(Q_{ji}^{''*}Q_{ij}^{''} + Q_{ij}^{''}Q_{ji}^{''*}) + \sin^2\alpha(S_{ji}^{''*}S_{ij}^{''} + S_{ij}^{''}S_{ji}^{''*}) \\ &+ \cos\alpha\sin\alpha(Q_{ji}^{''*}S_{ij}^{''} + S_{ji}^{''*}Q_{ij}^{''} + Q_{ij}^{''}S_{ji}^{''*} + S_{ij}^{''}Q_{ji}^{''*}) - [2m_{\widetilde{\chi}_i^+}m_{\widetilde{\chi}_j^+}][\cos^2\alpha[(Q_{ji}^{''*})^2 \\ &+ (Q_{ij}^{''})^2] + \sin[(S_{ji}^{''*})^2 + (S_{ij}^{''})^2] + \cos\alpha\sin\alpha(Q_{ji}^{''*}S_{ji}^{''*} + S_{ji}^{''*}Q_{ji}^{''*} + Q_{ij}^{''}S_{ij}^{''} + S_{ij}^{''}Q_{ij}^{''})]\}.\end{aligned}$$

Introducing the expressions of $|\overline{\mathscr{M}}|^2$, P_f as well as the factors η_k, $(1+\delta_{ij})$ and λ (with the conditions expressed before) in the equation (2), we find

$$\begin{aligned}\Gamma(H^0 \to \widetilde{\chi}_i^+\widetilde{\chi}_j^+) &= \frac{\mathsf{g}^2\lambda^{\frac{1}{2}}}{16\pi M_{H^0}^3(1+\delta(i,j))}\{[\cos^2\alpha[(Q_{ij}^{''})^2 + (Q_{ji}^{''})^2] + 2\cos\alpha\sin\alpha(Q_{ij}^{''}S_{ij}^{''} + \\ & Q_{ji}^{''}S_{ji}^{''}) + \sin^2\alpha[(S_{ij}^{''})^2 + (S_{ji}^{''})^2]][M_{H^0}^2 - m_{\widetilde{\chi}_i^+}^2 - m_{\widetilde{\chi}_j^+}^2] \\ & -4m_{\widetilde{\chi}_i^+}\, m_{\widetilde{\chi}_j^+}[\cos^2\alpha\ (Q_{ij}^{''})(Q_{ji}^{''}) \\ & + \cos\alpha\sin\alpha(Q_{ij}^{''}S_{ji}^{''} + S_{ij}^{''}Q_{ji}^{''}) + \sin^2\alpha(S_{ij}^{''})(S_{ji}^{''})]\}.\end{aligned} \tag{8}$$

This expression is that obtained for partial decay width of the process $\Gamma(H^0 \to \widetilde{\chi}_i^+\widetilde{\chi}_j^+)$. An equivalent equation of (8), can be calculated following the same form as in equations (5) and (6), that is:

$$F_{ijH^0} = \frac{1}{\varepsilon_i}[\cos\alpha Q_{ij}^{''} + \sin\alpha S_{ij}^{''}] \tag{9}$$

$$F_{jiH^0} = \frac{1}{\varepsilon_j}[\cos\alpha Q_{ji}^{''} + \sin\alpha S_{ji}^{''}]. \tag{10}$$

When these factors are substituted in the equation (8), yield

$$\begin{aligned}\Gamma(H^0 \to \widetilde{\chi}_i^+\widetilde{\chi}_j^+) &= \frac{\mathsf{g}^2\lambda^{\frac{1}{2}}}{16\pi M_{H^0}^3(1+\delta(i,j))}\Big((F_{ijH^0}^2 + F_{jiH^0}^2)(M_{H^0}^2 - m_{\widetilde{\chi}_i^+}^2 - m_{\widetilde{\chi}_j^+}^2) \\ & -4F_{ijH^0}F_{jiH^0}\varepsilon_i\varepsilon_j\eta_{H^0}m_{\widetilde{\chi}_i^+}m_{\widetilde{\chi}_j^+}\Big).\end{aligned} \tag{11}$$

This is the final equation for $\Gamma(H^0 \to \widetilde{\chi}_i^+\widetilde{\chi}_j^+)$. A similar procedure to the previous one, is used for the computation of the decays widths of the processes $h^0 \to \widetilde{\chi}_i^+\widetilde{\chi}_j^+$, $A^0 \to \widetilde{\chi}_i^+\widetilde{\chi}_j^+$.

We can say that, the results obtained with respect to computation of the partial decay width of the processes $H^0 \to \widetilde{\chi}_i^0 \widetilde{\chi}_j^0$, $h^0 \to \widetilde{\chi}_i^0 \widetilde{\chi}_j^0$, $A^0 \to \widetilde{\chi}_i^0 \widetilde{\chi}_j^0$, $H^0 \to \widetilde{\chi}_i^+ \widetilde{\chi}_j^+$, $h^0 \to \widetilde{\chi}_i^+ \widetilde{\chi}_j^+$, $A^0 \to \widetilde{\chi}_i^+ \widetilde{\chi}_j^+$ in the MSSM, are consistent with those found in the literature [4]. Think that this kind of processes are viable to carry out them in LHC, the which would launch important proofs on the existence of SUSY.

CONCLUSIONS

In this work, we studied the possible invisible decays of the Higg boson, in the frame of MSSM. From the results found, we see that the space of necessary parameters to consider the study of different decay scenarios are: $\tan_\beta$, μ, M, m_A, and α; which will serve as a proposal for the detection of the Higgs boson spectrum in LHC.

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