Branching ratio of the invisible decays of the lightest Higgs boson $h^0$ in the MSSM

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Abstract. The Supersymmetric models predicts the existence of light neutralinos with masses around 50 GeV as good candidates for detection of physics beyond the Standard Model, as well as other supersymmetric particles for different channels of Higgs boson decays. It this work, we presented the branching ratios of the lightest Higgs boson to neutralinos and charginos in the context of the Minimal Supersymmetric Standard Model. Although the invisible modes have been studied previously, is not known in detail the region of parameter space for supersymmetric sector where the mode reaches a significant branching ratio. We presented the analysis the parameters space looking for these regions by sampling techniques.
1. Introduction

Supersymmetry (SUSY) is a generalization of the space-time symmetries of quantum field theory that transforms fermions into bosons and vice versa [1]. At present, there is no experimental evidence that nature is supersymmetric. If supersymmetry were an exact symmetry in nature, then particles and their superpartners (which differ in spin by half a unit) would be degenerate in mass. Since this is not observed in data, supersymmetry cannot be an exact symmetry and must be broken. If we have supersymmetric theories at low energies, the electroweak scale is linked to the effective scale of the breaking of supersymmetry, both scales are characterized by the vacuum expectation value of the Higgs field (246 GeV). It is possible that supersymmetry will ultimately explain the origin of the large hierarchy of energy scales from the $W$ and $Z$ masses to the Planck scale.

2. Basic Concepts of the MSSM

The most economical candidate for a realistic SUSY model with a gauge group $SU(3) \times SU(2) \times U(1)$, and a minimal content of particles is the Minimal Supersymmetric Standard Model (MSSM) [1]. This model consists of taking the Standard Model and adding the corresponding supersymmetric partners [1]. In addition, the MSSM contains two hypercharge $Y = \pm 1$ Higgs doublets, which is the minimal structure for the Higgs sector of an anomaly-free supersymmetric extension of the Standard Model. The supersymmetric structure of the theory also requires (at least) two Higgs doublets to generate mass for both “up”-type and “down”-type quarks (and charged leptons) [6]. All renormalizable supersymmetric interactions consistent with (global) B-L conservation (B=baryon number and L=lepton number) are included [2].

As a consequence of B-L invariance, the MSSM possesses a multiplicative $R$-parity invariance, where $R = (-1)^{3(B-L)} + 2S$ for a particle of spin $S$. Note that this implies that all the ordinary Standard Model particles have even $R$ parity, whereas the corresponding supersymmetric partners have odd $R$ parity. The conservation of $R$ parity in scattering and decay processes has a crucial impact on supersymmetric phenomenology. For example, starting from an initial state involving ordinary ($R$- even) particles, it follows that supersymmetric particles must be produced in pairs. In general, these particles are highly unstable and decay into lighter states. However, $R$ parity invariance also implies that the lightest supersymmetric particle (LSP) is absolutely stable, and must eventually be produced at the end of a decay chain initiated by the decay of heavy unstable supersymmetric particle [3].

3. Neutralino sector

The higgsinos and electroweak gauginos mix with each other to produce the mass eigenstates that could be detected experimentally. The neutral higgsinos ($\tilde{H}_1^0$ and
Branching ratio of the invisible decays of the lightest Higgs boson $h_0$ in the MSSM and the neutral gauginos ($\tilde{\chi}_0^2$ and $\tilde{\chi}_0^2$) combine to form four mass eigenstates called neutralinos [4].

The charged higgsinos ($\tilde{\chi}_1^+$ and $\tilde{\chi}_2^-$) and winos ($\tilde{\chi}_1^+$ and $\tilde{\chi}_2^-$) mix to form two mass eigenstates with charge $\pm 1$ called charginos. We will denote the neutralino and chargino mass eigenstates by $\tilde{\chi}_i^0$ ($i = 1, 2, 3, 4$) and $\tilde{\chi}_i^\pm$ ($i = 1, 2$). By convention, these are labeled in ascending order, so that $m_{\tilde{\chi}_1^0} < m_{\tilde{\chi}_2^0} < m_{\tilde{\chi}_3^0} < m_{\tilde{\chi}_4^0}$ and $m_{\tilde{\chi}_1^\pm} < m_{\tilde{\chi}_2^\pm}$. The lightest neutralino, $\tilde{\chi}_1^0$, is usually assumed to be the LSP, unless there is a lighter gravitino or unless R-parity is not conserved, through it is the only a MSSM particle that can make a good dark matter candidate.

The neutralinos are determined by diagonalizing the corresponding mass matrix. In the minimal supersymmetric model the corresponding mass matrix depends on three unknown mass scales, namely, $\mu$, $M_2$ and $M_1$, and on the ratio $\tan \beta \equiv v_2/v_1$, where $v_2(v_1)$ is the vacuum expectation value of the Higgs field which couples to the up-type quarks (down-type quarks); $\mu$ is the supersymmetric Higgs-boson-mass parameter; and $M_2$ and $M_1$ are the gaugino mass parameters associated with the SU(2) and U(1) subgroups of the standard model. It is common to reduce the parameter freedom by assuming that $M_2$ and $M_1$ are related to the gaugino mass $M_3$ of the SU(3) [5].

4. Higgs sector

Supersymmetry imposes new requirements on the theory regarding the structure of the Higgs boson. In order to supersymmetric theories don’t show anomalies, two Higgs doublets are required and so the theory is renormalizable. It is known that within the standard model only one Higgs doublet is required to give mass to quarks and leptons, while in the MSSM two Higgs doublets ($\tilde{H}_1^0, \tilde{H}_2^0$) and ($\tilde{H}_1^0, \tilde{H}_2^0$) are required to give mass to up-type quarks and down-type quarks and the corresponding leptons. Therefore, this model contains two Higgs doublets [6]. The MSSM considers five physical Higgs particles: a pair of charged scalar Higgs bosons $H^\pm$, two CP-even neutral scalar Higgs bosons $h^0$ and $H^0$ (by convention is taken $m_{H^0} \geq m_{h^0}$) and finally a CP-odd pseudoscalar neutral Higgs boson $A^0$ (in this paper its mass is denoted as $m_A$). The three neutral Higgs bosons are determined by the diagonalization of the mass matrix of neutral Higgs bosons, which depends on the Higgs potential.

5. Results and conclusions

Decays of neutral Higgs bosons to charginos neutralinos are important in order to determine the branching ratios of the different supersymmetric decay channels. There exists a considerable probability for the Higgs boson decays into a pair of lighter supersymmetric particles $h^0 \rightarrow \tilde{\chi}_i \tilde{\chi}_j$ (LSP lightest neutralino). The LSP could be almost degenerate with other charged states (charginos), which the Higgs boson can decay, and thus the product of the charged states are too weak to be detected. If $R$-parity is conserved, the LSP $\tilde{\chi}_i$ (neutralino or chargino lightest) doesn’t decay and escapes the detection. Therefore, the Higgs boson is invisible [7].
In the following, we present the results obtained at loop-level for the lightest neutralino masses \( \tilde{\chi}_1^0 \) \( (m_{\tilde{\chi}_1^0}) \), the masses of neutral Higgs boson lightest \( h^0 \) \( (m_{h^0}) \) and the branching ratio of the possible decays of \( h^0 \) in the MSSM. These results are obtained using the program HDECAY [8].

Taking into account the bounds of mass of 90 GeV for chargino and the lightest Higgs boson \( (\tilde{\chi}_1^\pm \) and \( h^0) \), a search of data was carried out where the branching ratios for the decay \( h^0 \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0 \) (BRANEU) may be more dominant.

With the mass bounds imposed for \( h^0 \) and \( \tilde{\chi}_1^\pm \), and the parameters range 50 GeV \( \leq m_A \leq 1000 \) GeV, \( 2 \leq \tan \beta \leq 50 \), and \( 100 \) GeV \( \leq \mu \leq 1000 \) GeV, we are maintaining the parameter \( M = 100 \) GeV fixed; and two graphs were made. It was find the masses of \( \tilde{\chi}_1^0 \) as function of the parameters \( \mu \) and \( \tan \beta \), and also the branching ratios of the possible decay channels of \( h^0 \), which are as function of the masses of \( h^0 \). These plots are located in Figure 1. With these same parameters in the same range except \( 0.5 \leq \tan \beta \leq 50 \), another search was made of the branching ratios of the different decay channels of \( h^0 \).

The results obtained are contained in Figure 2 and values for the different parameters are reported in Table 1.

The Figure 2 shows the behavior of the branching ratios for different decay channels of the lightest Higgs boson \( h^0 \) as function of \( m_{h^0} \), where the maximum value of the BRANEU is 0.06 and the mass obtained for the neutralinos are in a range of 45.38 to 47.94 GeV that falls within the bounds of mass for the neutralinos.

After having carried out a study of possible decay channels for the decay of the lightest neutral Higgs boson in the MSSM, it is concluded that the decay of the Higgs
Figure 2. Branching ratios of different decay channels of the lightest Higgs boson $h^0$, with $M = 100$ GeV fixed, and $100$ GeV $\leq \mu \leq 1000$ GeV; $50$ GeV $\leq m_A \leq 1000$ GeV; $0.5 \leq \tan \beta \leq 50$.

| $\tan \beta$ | $\mu$ [GeV] | $M$ [GeV] | $m_{\tilde{\chi}_1^0}$ [GeV] | $m_{\tilde{\chi}_1^+}$ [GeV] | $BRA-$ NEU | $m_A$ [GeV] | $M_{h^0}$ [GeV] |
|---|---|---|---|---|---|---|---|
| 6 | 400 | 100 | 45.71 | 90.69 | 0.06 | 1000 | 114.4 |

Table 1. Mass values for lightest neutralino $\tilde{\chi}_1^0$, chargino $\tilde{\chi}_1^+$ and Higgs boson $h^0$ corresponding to values in which is reached the best branching ratio for the decay $h^0 \rightarrow \tilde{\chi}_1^0\tilde{\chi}_1^0$.

bosons are dominant in invisible modes in different regions of the parameter space, hence the importance in continuing their study to better understand the supersymmetric spectrum.

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