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HIGGS BOSON DECAYS TO NEUTRALINOS AND CHARGINOS IN THE NMSSM

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Abstract. Within the framework of the Next-To-Minimal Supersymmetric Standard Model (NMSSM), we present the Feynman diagrams as well as the explicit formulas for the decay width of neutral Higgs boson to two charginos and two neutralinos. The importance of these decays is that they may have sizeable probability that the Higgs boson decays into LSPs.

1. Introduction

In this work we study the Next-to-Minimal Supersymmetric Standard Model (NMSSM) in which a singlet Higgs superfield is added to the two doublet superfields that are present in the minimal extension (MSSM) [1], [2].

The addition of a $SU(3) \times SU(2) \times U(1)$ gauge singlet supermultiplet to the MSSM has been motivated by several issues: (i) the solution of the so-called μ-problem; (ii) the possibility of spontaneous breaking of the CP symmetry; (iii) the upper limits on the Higgs mass that are relatively low in the MSSM could be relaxed; (iv) the neutral particle spectrum is enriched by two scalars and one fermion, which could mix with other Higgs bosons and neutralinos and modify their physical properties; (v) possible deviations from the MSSM could urge to enlarge the experimental searches, which have been centred upon the MSSM. We refer here to the supersymmetric model with a gauge singlet in its simplest version, the NMSSM [2], [4]. As compared to the MSSM, the NMSSM can induce a richer phenomenology in the Higgs and neutralino sectors.

2. Generalities

One of the most attractive supersymmetric models is the Next to Minimal Supersymmetric Standard Model [5] which extends the MSSM by the introduction of just one singlet superfield, $\widehat{S}$. When the scalar component of $\widehat{S}$ acquires a TeV scale vacuum expectation value (a very natural result in the context of the model), the superpotential term $\lambda\widehat{S}\widehat{H}_u\widehat{H}_d$ generates an effective $\mu\widehat{H}_u\widehat{H}_d$ interaction for the Higgs doublet superfields with $\mu = \lambda\langle S\rangle$. Such a term is essential for acceptable phenomenology. No other SUSY model generates this crucial component of the superpotential in as natural a fashion [6]. The additional singlet superfield of the NMSSM leads to extended Higgs and neutralino sectors.

The Higgs sector of the NMSSM consists of the usual two Higgs doublets H_u and H_d and an extra Higgs singlet $\widehat{S}$. The extra singlet field is allowed to couple only to the Higgs doublets of the model, the supersymmetrization of which is that the singlet field only couples to the Higgsino doublets. Consequently, the couplings of the singlet $\widehat{S}$ to gauge bosons and fermions will only be manifest via their mixing with the doublet Higgs fields. After the Higgs fields take on the VEV's and rotating away the Goldstone modes, we are left with a pair of charged Higgs bosons, 3 real scalar fields, and 2 pseudoscalar fields [7]. Therefore the Higgs sector of the NMSSM contains five physical neutral Higgs bosons, three Higgs scalars $S_a = h_a$ (with $a = 1, 2, 3$) and two pseudoscalars $P_\alpha = h_\alpha$ (with $\alpha = 1, 2$), and two degenerate physical charged Higgs particles $H^\pm$.

In contrast to the Higgs sector, the neutralino sector 2 is complemented only by the familiar SU(2) and U(1) gaugino mass terms, resulting in a much less complex parameter space. The extra singlet superfield adds an extra higgsino to the spectrum, often called a singlino, resulting in five neutralino states [8], [9].

With fixed parameters of the Higgs sector the masses and mixings of the neutralinos are determined by the two further parameters M and M' of the Lagrangian

$$\begin{aligned} \mathcal{L}_{m_{\tilde{\chi}_i^0}} &= \frac{1}{\sqrt{2}} ig\lambda^3(v_1\psi^1_{H_1} - v_2\psi^2_{H_2}) - \frac{1}{\sqrt{2}} ig'\lambda'(v_1\psi^1_{H_1} - v_2\psi^2_{H_2}) \\ &\quad -\frac{1}{2}M\lambda^3\lambda^3 - \frac{1}{2}M'\lambda'\lambda' \\ &\quad -\lambda x\psi^1_{H_1}\psi^2_{H_2} - \lambda v_1\psi^2_{H_2}\psi_N - \lambda v_2\psi^1_{H_1}\psi_N + kx\psi^2_N + h.c. \end{aligned} \tag{1}$$

In the basis

$$(\psi^0)^T = (-i\lambda_\gamma,\ -i\lambda_Z,\ \psi^a_H,\ \ \psi^b_H,\ \psi_N) \tag{2}$$

with

$$\begin{aligned} \psi^a_H &= \psi^1_{H_1}\cos\beta - \psi^2_{H_2}\ \mathrm{sen}\,\beta, \\ \psi^b_H &= \psi^1_{H_1}\ \mathrm{sen}\,\beta + \psi^2_{H_2}\cos\beta, \end{aligned} \tag{3}$$

the mass term of the Lagrangian reads like

$$\mathcal{L}_{m_{\tilde{\chi}_i^0}} = -\frac{1}{2}(\psi^0)^T \mathbf{Y}\psi^0 + H.c.. \tag{4}$$

The symmetric neutralino mixing matrix is given as

$$\mathbf{Y} = \begin{pmatrix} -Ms^2_W - M'c^2_W & (M'-M)s_Wc_W & 0 & 0 & 0 \\ (M'-M)s_Wc_W & -Mc^2_W - M's^2_W & m_Z & 0 & 0 \\ 0 & m_Z & -\lambda x\ \mathrm{sen}\,2\beta & \lambda x\cos 2\beta & 0 \\ 0 & 0 & \lambda x\cos 2\beta & \lambda x\ \mathrm{sen}\,2\beta & \lambda v \\ 0 & 0 & 0 & \lambda v & -2kx \end{pmatrix}.$$

It can be diagonalized by a unitary 5×5 matrix $\mathcal{N}$

$$\mathcal{N}\mathbf{Y}\mathcal{N}^{-1} = \begin{pmatrix} m_{\tilde{\chi}^0_1} & 0 & 0 & 0 & 0 \\ 0 & m_{\tilde{\chi}^0_2} & 0 & 0 & 0 \\ 0 & 0 & m_{\tilde{\chi}^0_3} & 0 & 0 \\ 0 & 0 & 0 & m_{\tilde{\chi}^0_4} & 0 \\ 0 & 0 & 0 & 0 & m_{\tilde{\chi}^0_5} \end{pmatrix} = \mathbf{m}_{\tilde{\chi}^0_\mathbf{i}}, \tag{5}$$

with real and positive mass eigenvalues $\mathbf{m}_{\widetilde{\chi}^0_i}$. If one tolerates negative eigenvalues, the diagonalization matrix can be chosen to be real. Then the absolute values of $m_{\widetilde{\chi}^0_i} \gtrless 0$ are the physical neutralino masses. The upper 4×4 matrix of Y represents the neutralino mixing matrix of the MSSM with $\mu = \lambda x$ [10]. The remaining particle content is identical with that of the MSSM.

3. Decay widths

In this section we expose the *decay rate* Γ (the probability per unit time of carrying out a particular process [11]) and Feynman diagrams for the coupling of the neutral Higgs bosons to pairs of neutralinos and charginos in the NMSSM.

The formulas for the decay widths of a scalar or pseudoscalar Higgs boson into two neutralinos [12]:

$$\begin{aligned}\Gamma(h_a \to \widetilde{\chi}^0_i \widetilde{\chi}^0_j) &= \frac{g^2 \lambda^{\frac{1}{2}}}{16\pi M^3_{h_a}(1+\delta(i,j))} \Bigg[\left(\frac{1}{g^2} \left[(Q^{L''}_{aij})^2 + (Q^{L''}_{aji})^2 \right] \right) \\ &\times \left(M^2_{h_a} - m^2_{\widetilde{\chi}^0_i} - m^2_{\widetilde{\chi}^0_j} \right) - \left[4 m_{\widetilde{\chi}^0_i} m_{\widetilde{\chi}^0_j} \right] \\ &\times \left[\frac{1}{g^2} \left(Q^{L''}_{aij} \right) \left(Q^{L''}_{aji} \right) \right] \Bigg] \end{aligned} \tag{6}$$

$$\begin{aligned}\Gamma(h_\alpha \to \widetilde{\chi}^0_i \widetilde{\chi}^0_j) &= \frac{g^2 \lambda^{\frac{1}{2}}}{16\pi M^3_{h_\alpha}(1+\delta(i,j))} \Bigg[\left(\frac{1}{g^2} \left[(R^{L''}_{\alpha ij})^2 + (R^{L''}_{\alpha ji})^2 \right] \right) \\ &\times \left(M^2_{h_\alpha} - m^2_{\widetilde{\chi}^0_i} - m^2_{\widetilde{\chi}^0_j} \right) + \left[4 m_{\widetilde{\chi}^0_i} m_{\widetilde{\chi}^0_j} \right] \\ &\times \left[\frac{1}{g^2} \left(R^{L''}_{\alpha ij} \right) \left(R^{L''}_{\alpha ji} \right) \right] \Bigg] \end{aligned} \tag{7}$$

The decay of a scalar or pseudoscalar Higgs boson into two charginos

$$\begin{aligned}\Gamma(h_a \to \widetilde{\chi}^+_i \widetilde{\chi}^-_j) &= \frac{g^2 \lambda^{\frac{1}{2}}}{16\pi M^3_{h_a}(1+\delta(i,j))} \Bigg[\left(\frac{1}{g^2} \left[(Q_{aij})^2 + (Q_{aji})^2 \right] \right) \\ &\times \left(M^2_{h_a} - m^2_{\widetilde{\chi}^+_i} - m^2_{\widetilde{\chi}^-_j} \right) - \left[4 m_{\widetilde{\chi}^+_i} m_{\widetilde{\chi}^-_j} \right] \\ &\times \left[\frac{1}{g^2} \left(Q_{aij} \right) \left(Q_{aji} \right) \right] \Bigg] \end{aligned} \tag{8}$$

$$\begin{aligned}\Gamma(h_\alpha \to \widetilde{\chi}^+_i \widetilde{\chi}^-_j) &= \frac{g^2 \lambda^{\frac{1}{2}}}{16\pi M^3_{h_\alpha}(1+\delta(i,j))} \Bigg[\left(\frac{1}{g^2} \left[(R_{\alpha ij})^2 + (R_{\alpha ji})^2 \right] \right) \\ &\times \left(M^2_{h_\alpha} - m^2_{\widetilde{\chi}^+_i} - m^2_{\widetilde{\chi}^-_j} \right) + \left[4 m_{\widetilde{\chi}^+_i} m_{\widetilde{\chi}^-_j} \right] \\ &\times \left[\frac{1}{g^2} \left(R_{\alpha ij} \right) \left(R_{\alpha ji} \right) \right] \Bigg] \end{aligned} \tag{9}$$

In Figure 1, we can shown the Feynman diagrams for the following couplings: (i) when neutral scalar Higgs bosons decay into pairs of neutralinos the processes that occur are $\Gamma(h_a \to \widetilde{\chi}^0_i \widetilde{\chi}^0_j)$,

($a = 1, 2, 3$); and (*ii*) the neutral pseudoscalar Higgs bosons processes are $\Gamma(h_\alpha \to \widetilde{\chi}_i^0 \widetilde{\chi}_j^0)$ ($\alpha = 1, 2$).

For the case in which the neutral scalar Higgs bosons decay into pairs charginos the processes presented are: (*i*) $\Gamma(h_a \to \widetilde{\chi}_i^+ \widetilde{\chi}_j^-)$; and (*ii*) the neutral pseudoscalar Higgs bosons $\Gamma(h_\alpha \to \widetilde{\chi}_i^+ \widetilde{\chi}_j^-)$.

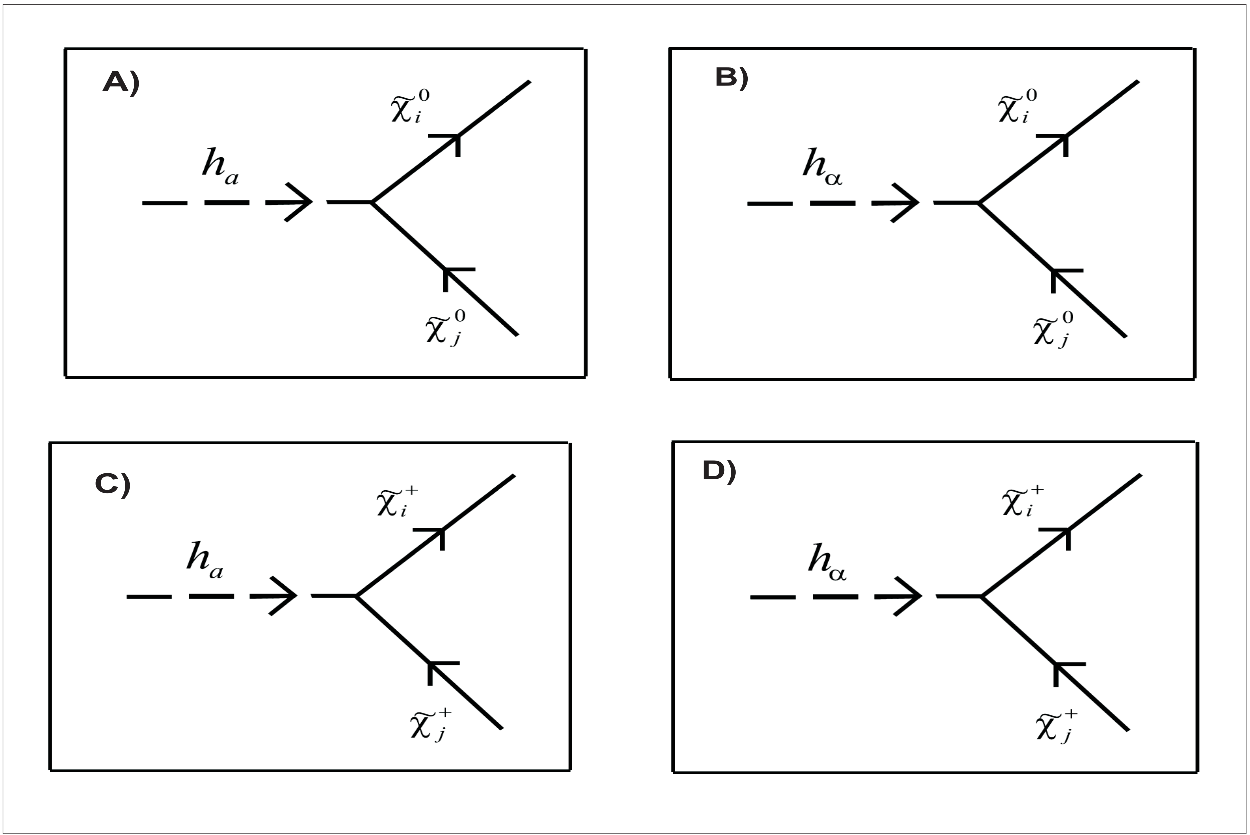

Figure 1. Feynman diagrams for the couplings of a scalar or pseudoscalar Higgs boson to two neutralinos ((A) and (B)) and two charginos ((C) and (D)).

4. Conclusion

The search for important particles such as Higgs bosons, leads to develop an exhaustive study on the possible decays in supersymmetric models like the NMSSM. In the framework of the basic supersymmetric model NMSSM, the decay width was calculated for the couplings of neutral Higgs bosons to charginos and neutralinos, recovering the equations decay widths incontrend in the literature for this kind of processes. A contribution of this work is to have obtained the formula that determines the decay width for neutral Higgs bosons in charginos.

5. References

[1] A. Djouadi *et al*, JHEP **0807**, 002 (2008) [arXiv:0801.4321].
[2] H. K. Dreiner, F. Staub and A. Vicente, Phys. Rev. D **87**, 035009 (2013) [arXiv:1211.6987].
[3] U. Ellwanger, M. Rausch de Traubenberg and C. A. Savoy, Nucl. Phys. B **492**, 21 (1997) [arXiv:9611251].
[4] S. F. King, M. Muhlleitner, R. Nevzorov and K. Walz, Nucl. Phys. B **870**, 323 (2013) [arXiv:1211.5074].
[5] J. F. Gunion and H. E. Haber, Nucl. Phys. B **272**, (1986).
[6] U. Ellwanger, J. F. Gunion and C. Hugonie, JHEP **0507**, 041 (2005) [arXiv:0503203].

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[7] K. Cheung and T. -J. Hou, Phys. Lett. B **674**, 54 (2009) [arXiv:0809.1122].
[8] D. J. Miller [arXiv:0410227].
[9] D. A. Vasquez, G. Belanger, C. Boehm, A. Pukhov and J. Silk, Phys. Rev. D **82**, 115027 (2010) [arXiv:1009.4380].
[10] F. Franke and H. Fraas, Int. J. Mod. Phys. A **12**, 479 (1997) [arXiv:9512366].
[11] David Griffiths, *Introduction to elementary particles*, Wiley, New York, 198.
[12] F. Franke and H. Fraas, Z. Phys. C **72**, 309 (1996) [arXiv:9511275].