

Phenomenology of non-universal gaugino masses and implications for the Higgs boson decay

K HUITU^{1,2}, J LAAMANEN^{1,2}, P N PANDITA^{3,*} and SOUROV ROY²

¹High Energy Physics Division, Department of Physical Sciences, University of Helsinki,
P.O. Box 64, FIN-00014, Finland

²Helsinki Institute of Physics, University of Helsinki, P.O. Box 64, FIN-00014, Finland

³ Department of Physics, North-Eastern Hill University, Shillong 793 022, India

*E-mail: pandita@sancharnet.in

Abstract. Grand unified theories (GUTs) can lead to non-universal gaugino masses at the unification scale. We study the implications of such non-universal gaugino masses for the composition of the lightest neutralino in supersymmetric (SUSY) theories based on $SU(5)$ gauge group. We also consider the phenomenological implications of non-universal gaugino masses for the phenomenology of Higgs bosons in the context of large hadron collider.

Keywords. Supersymmetry; non-universal gaugino masses; Higgs bosons.

PACS Nos 12.60.Jv; 11.30.Er; 14.80.Ly

1. Introduction

It is widely expected that some of the supersymmetric partners of the standard model (SM) particles will be produced at the CERN large hadron collider (LHC), which is going to start operation in a few years time. In the experimental search for supersymmetry the lightest SUSY particle will play a crucial role since the heavier SUSY particles will decay into it. In SUSY models with R -parity conservation, the lightest SUSY particle is absolutely stable [1]. In most of the SUSY models the lightest neutralino ($\tilde{\chi}_1^0$), which is an admixture of gauginos and higgsinos, is the lightest SUSY particle (LSP). Such an LSP is also a particle dark matter candidate [2]. From the point of view of experimental discovery of supersymmetry at a collider like the LHC, the LSP is the only SUSY particle in the final product of the cascade decay of a heavy SUSY particle.

In this work [3] we will assume that the LSP is the lightest neutralino, and that it escapes the collider experiments undetected. The cascade chain will typically contain other neutralinos ($\tilde{\chi}_j^0$, $j = 2, 3, 4$) as well as charginos ($\tilde{\chi}_i^\pm$, $i = 1, 2$). The charginos are an admixture of charged gauginos and charged higgsinos. The composition and mass of the neutralinos and charginos will play a key role in the

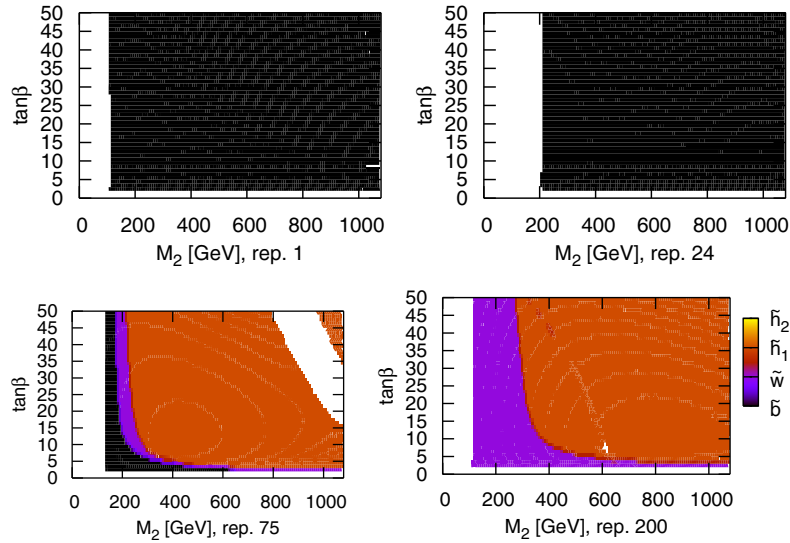


Figure 1. Main component of the lightest neutralino in different representations of $SU(5)$ that arise in the product (2).

search for SUSY particles. The mass patterns of the neutralinos in different SUSY models were considered in detail in [4,5].

Although most of the phenomenological studies involving neutralinos and charginos have been performed with universal gaugino masses at the GUT scale, there is no compelling theoretical reason for such a choice. Thus, it is important to investigate the changes in the experimental signals for supersymmetry with the changes in the composition of neutralinos and charginos that may arise because of the changes in the underlying boundary conditions at the grand unification scale. In this paper we shall study the implications of the non-universal gaugino masses for the phenomenology of neutral Higgs bosons in a $SU(5)$ supersymmetric grand unified theory.

2. Non-universal gaugino masses in supersymmetric $SU(5)$

The masses and the compositions of neutralinos and charginos are determined by the soft SUSY breaking gaugino masses M_i ($i = 1, 2, 3$), the Higgs mixing parameter μ , and the ratio of the Higgs vacuum expectation values $\tan\beta$. In general, the gaugino masses need not be equal at the GUT scale. In SUSY models, such as $SU(5)$ grand unified models, non-universal gaugino masses are generated by a non-singlet chiral superfield Φ^n that appears linearly in the gauge kinetic function $f(\Phi)$ which is an analytic function of the chiral superfields Φ in the theory [6]. When the F -component of Φ , F_Φ , gets a VEV $\langle F_\Phi \rangle$, it generates the gaugino masses ($\lambda^{a,b}$ are gaugino fields):

Table 1. Ratios of the gaugino masses at the GUT scale, and at the electroweak scale in the normalization $M_3(\text{GUT}) = 1$, $M_3(\text{EW}) = 1$.

F_Φ	M_1^G	M_2^G	M_3^G	M_1^{EW}	M_2^{EW}	M_3^{EW}
1	1	1	1	0.14	0.29	1
24	-0.5	-1.5	1	-0.07	-0.43	1
75	-5	3	1	-0.72	0.87	1
200	10	2	1	1.44	0.58	1

$$\mathcal{L}_{\text{g.k.}} \supset \frac{\langle F_\Phi \rangle_{ab}}{M_{\text{P}}} \lambda^a \lambda^b + \text{h.c.}, \quad (1)$$

where g.k. stands for gauge kinetic term. Since the gauginos belong to the adjoint representation of $SU(5)$ with

$$(\mathbf{24} \otimes \mathbf{24})_{\text{symm}} = \mathbf{1} \oplus \mathbf{24} \oplus \mathbf{75} \oplus \mathbf{200}, \quad (2)$$

Φ and F_Φ can belong to, besides the singlet, any of the non-singlet representations **24**, **75** and **200** of $SU(5)$. For the non-singlet case these gaugino masses are unequal but related to one another [7]. In table 1, we show the ratios of the resulting gaugino masses at the GUT scale and the electroweak scale. In figure 1, we show the dominant component of the lightest neutralino (LSP) for the four representations as a function of $\tan\beta$ and M_2 (calculated at the electroweak scale) for the value of soft SUSY breaking scalar mass $m_0(\text{GUT}) = 1$ TeV. For the case of the singlet and **24** representation, the dominant component is always the bino. For the **75** dimensional representation, the situation is complicated, and for the **200** dimensional representation the LSP is either a wino or a higgsino, depending on the values of M_2, μ and $\tan\beta$.

3. Higgs detection using $H^0, A^0 \rightarrow \tilde{\chi}_2^0 \tilde{\chi}_2^0 \rightarrow 4l$

It is usually assumed that SUSY partners are too heavy so that Higgs bosons cannot decay into SUSY particles. However, it may be that for the heavy Higgs bosons H^0, A^0 and H^\pm the decays to SUSY particles are important or even dominant. Here we will study the decay chain

$$H^0, A^0 \rightarrow \tilde{\chi}_2^0 \tilde{\chi}_2^0, \quad \tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 l^+ l^-, \quad l = e, \mu, \quad (3)$$

for four different representations of $SU(5)$ in (2). The decay $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 l^+ l^-$ depends on the parameters M_2, M_1, μ and $\tan\beta$, which control the neutralino masses and the mixing parameters, and also on the slepton masses $m_{\tilde{l}}$. As long as the direct decay of $\tilde{\chi}_2^0$ into $\tilde{\chi}_1^0 + Z^0$ is suppressed and the sleptons are heavier than $\tilde{\chi}_2^0$, three-body decays of $\tilde{\chi}_2^0$ into charged leptons and $\tilde{\chi}_1^0$ will be significant. In figure 2 we show a typical branching ratio of the three-body decay (3) as a function of $\tan\beta$ for the **1**, **75** and **200** representations, respectively. In this figure the initial value of $\tan\beta$ is 4.5, since for a lower value of $\tan\beta$ the light Higgs mass m_h is less

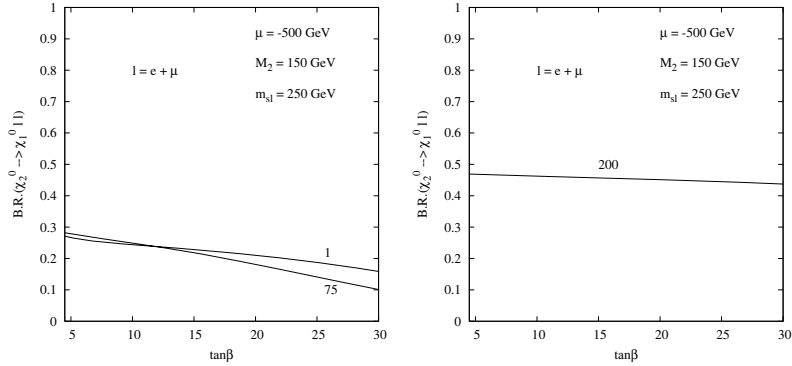


Figure 2. Branching ratio as a function of $\tan\beta$, with $m_{\tilde{l}} > m_{\tilde{\chi}_2^0}$, for the representations **1**, **75** and **200**.

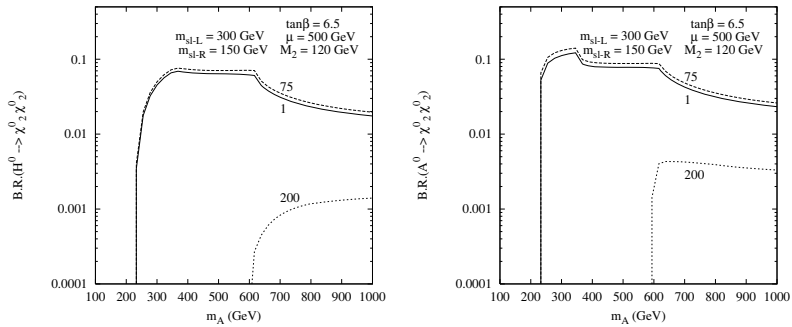


Figure 3. The branching ratio of $H^0, A^0 \rightarrow \tilde{\chi}_2^0 \tilde{\chi}_2^0$ as a function of m_A for three different $SU(5)$ representations in (2). Here $\tan\beta$ is taken to be 6.5.

than 114.4 GeV, which is the lower limit of LEP [8]. We see from the figure that for higher values of $\tan\beta$ this branching ratio decreases since the branching ratio $\tilde{\chi}_2^0 \rightarrow \tilde{\chi}_1^0 \tau^+ \tau^-$ increases with $\tan\beta$ due to a larger Yukawa coupling.

**4. Decay of heavy Higgs bosons into a pair of neutralinos:
 $H^0, A^0 \rightarrow \tilde{\chi}_2^0 \tilde{\chi}_2^0$**

Here we study the branching ratios of the heavy Higgs bosons H^0 and A^0 into a pair of second lightest neutralinos. The decay widths and the branching ratios depend on the ratio of M_1 and M_2 along with other MSSM parameters. We have calculated the branching ratio of $H^0, A^0 \rightarrow \tilde{\chi}_2^0 \tilde{\chi}_2^0$ for different $SU(5)$ representations that arise in the product (2). As an example, in figure 3, we have shown the dependence of branching ratio $\text{BR}(H^0, A^0 \rightarrow \tilde{\chi}_2^0 \tilde{\chi}_2^0)$ on m_A for a particular choice of MSSM parameters. We can see that for this choice of the parameter set and for $m_A < 350$ GeV, the branching ratio of the decay of A^0 is larger than that of the decay of the heavy Higgs scalar H^0 for the representations **1** and **75**. This is due to the fact that for H^0 the total decay width is larger due to the increase in the number

of available channels to the SM particles, which leads to a smaller branching ratio to sparticles. In the case of **200** dimensional representation the threshold opens up for heavier m_A , and once again the branching ratio of A^0 is larger than that of the H^0 . The results for the representation **24** is not shown here due to the fact that it results in the lightest neutralino mass below the current experimental limits.

References

- [1] M Drees and M Peskin, *Proceedings of SUSY04*, Tsukuba, Japan (<http://www-conf.kek.jp/susy04/plenary.html>)
- [2] See, for e.g. G Jungman, M Kamionkowski and K Griest, *Phys. Rep.* **267**, 195 (1996)
- [3] K Huitu, J Laamanen, P N Pandita and Sourov Roy, *Phys. Rev.* **D72**, 055013 (2005)
- [4] P N Pandita, *Phys. Rev.* **D53**, 566 (1996)
- [5] K Huitu, J Laamanen and P N Pandita, *Phys. Rev.* **D67**, 115009 (2003)
- [6] E Cremmer, S Ferrara, L Girardello and A Van Proeyen, *Phys. Lett.* **B116**, 231 (1982)
- [7] J R Ellis, K Enqvist, D V Nanopoulos and K Tamvakis, *Phys. Lett.* **B155**, 381 (1985)
- [8] R Barate *et al*, *Phys. Lett.* **B565**, 61 (2003)