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The MSSM with Non-Universal Higgs Masses [a]

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Abstract

I review a generalization of CMSSM/mSUGRA model in which the Higgs masses are let to be free, namely the Non Universal Higgs Masses (NUHM) model. In our study we explore this model by employing constraints from cosmology as well as from particle physics to restrict the parameter space. We also calculate the neutralino-proton cross section in the allowed regions.

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THE MSSM WITH NON-UNIVERSAL HIGGS MASSES

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I review a generalization of CMSSM/mSUGRA model in which the Higgs masses are let to be free, namely the Non Universal Higgs Masses (NUHM) model. In our study we explore this model by employing constraints from cosmology as well as from particle physics to restrict the parameter space. We also calculate the neutralino-proton cross section in the allowed regions.

1 Introduction

In the Constrained Minimal Supersymmetric Standard Model (CMSSM) or minimal Supergravity model (mSUGRA) all soft breaking scalar masses are set to be universal at the GUT scale. While the universality of the sfermion masses is motivated by GUT theories and FCNC problems, universality in the Higgs sector is less theoretically motivated. This inspires ones to generalize the CMSSM by letting the Higgs masses, m_1 and m_2, be non-universal. One can then choose the Higgs mixing parameter μ and the pseudoscalar Higgs mass m_A as free parameters. We call this model the Non Universal Higgs Masses (NUHM) model. We have been studying this model in several papers [1] and find that it has some new features not seen in the CMSSM. We also calculate the neutralino-proton cross section for the allowed regions to find the possible range of neutralino direct detection rate in this model.

2 The NUHM Model

The free parameters in the CMSSM are: the universal scalar mass m_0, the universal gaugino mass $m_{1/2}$, the universal trilinear coupling A_0, all three defined at the GUT scale, the ratio of the two Higgs vev $\tan\beta \equiv v_2/v_1$, and sign(μ) where μ is the Higgs mixing parameter. The magnitude of μ is determined by the electroweak symmetry breaking conditions

$$\begin{aligned} m_A^2 &= m_1^2 + m_2^2 + 2\mu^2 + \Delta_A \\ \mu^2 &= \frac{m_1^2 - m_2^2 \tan^2\beta + \frac{1}{2} m_{\text{ß}Z}^2 (1 - \tan^2\beta) + \Delta_\mu^{(1)}}{\tan^2\beta - 1 + \Delta_\mu^{(2)}} \,, \end{aligned} \tag{1}$$

where Δ_A and $\Delta_\mu^{(1,2)}$ are loop corrections and $m_{1,2}(M_{GUT}) = m_0$. In the NUHM m_1 and m_2 are no longer set equal to m_0 at the GUT scale. Thus we can use μ and the pseudoscalar Higgs mass m_A as our input parameters.

Solving for m_1^2 and m_2^2 we can see that, if m_A is too small or μ is too large, then m_1^2 and/or m_2^2 can become negative and large. This could lead to $m_1^2(M_{GUT}) + \mu^2(M_{GUT}) < 0$ and/or $m_2^2(M_{GUT}) + \mu^2(M_{GUT}) < 0$, which raises the question of vacuum stability as the universe evolved from high temperature to current temperature. The requirement that electroweak symmetry breaking occurs far below the GUT scale forces us to impose the conditions $m_{1,2}^2(M_{GUT}) + \mu^2(M_{GUT}) > 0$ as extra constraints, which we call the GUT stability constraints.[a]

There are terms in the RGE, collectively called the S-term:

$$\begin{aligned} S \equiv \frac{g_1^2}{4}(m_2^2 - m_1^2 + 2(m^2_{\widetilde{Q}_L} - m^2_{\widetilde{L}_L} - 2m^2_{\widetilde{u}_R} + m^2_{\widetilde{d}_R} + m^2_{\widetilde{e}_R}) \\ + (m^2_{\widetilde{Q}_{3L}} - m^2_{\widetilde{L}_{3L}} - 2m^2_{\widetilde{t}_R} + m^2_{\widetilde{b}_R} + m^2_{\widetilde{\tau}_R})) \,, \end{aligned} \tag{2}$$

which vanishes for universal model due to anomaly cancellation. However it is nonzero for NUHM model. Although we start with non-universality only in the Higgs sector, the sfermion mass spectrum is also affected trough the interconnected RG equations. The S-term appears, for example, in the slepton masses running as follows (neglecting the Yukawas)

$$\begin{aligned} \frac{dm^2_{\widetilde{L}_L}}{dt} &= \frac{1}{8\pi^2}(-3g_2^2 M_2^2 - g_1^2 M_1^2 - 2S) \\ \frac{dm^2_{\widetilde{e}_R}}{dt} &= \frac{1}{8\pi^2}(-4g_1^2 M_1^2 + 4S)\,. \end{aligned} \tag{3}$$

We can deduce immediately that if S is large and negative we could have $\widetilde{L}_L$ lighter that $\widetilde{e}_R$ which means that sneutrino could be the lightest supersymmetric particle (LSP).

In summary the possible LSP in the NUHM are the lightest neutralino χ, the lightest stau $\widetilde{\tau}_1$, right handed selectron $\widetilde{e}_{\mathrm{R}}$, sneutrinos $\widetilde{\nu}$ and the lightest stop $\widetilde{t}_1$ (for large $|A_0|$). However, sneutrino dark matter is mostly excluded [3], therefore we still assume that the viable LSP is neutralino. Furthermore since μ now is free we can have either bino-like or higgsino-like neutralino depending on the ratio of μ over $m_{1/2}$. Thus the important coannihilation processes are: $\chi - \widetilde{\ell}$ ($\ell = e,\, \mu,\, \tau$), $\chi - \widetilde{t}$, $\chi - \widetilde{\nu}_\ell$, and $\chi - \chi' - \chi^\pm$, plus all combinations for the overlap regions.

We impose in our analysis the constraints on the MSSM parameter space that are provided by direct sparticle searches at LEP, including that on the lightest chargino $\chi^\pm$: $m_{\chi^\pm} \gtrsim 103.5$ GeV, the selectron $\widetilde{e}$: $m_{\widetilde{e}} \gtrsim 99$ GeV, and the Higgs mass: $m_H > 114.4$ GeV. We also impose the constraint from measurements of $b \to s\gamma$, which agree with the Standard Model calculation. The latest value of the anomalous magnetic moment of the muon, a_μ, is also taken into account. However due to the still lingering uncertainty in

[a]For a different point of view, however, see [2].

the Standard Model calculation of a_μ, we do not impose this as an absolute constraint on the supersymmetric parameter space. These constraints and their corresponding references are discussed in more detail in [1].

3 Exploration of the Parameter Space

In Fig. 1 we plot a $\mu - m_A$ plane for $\tan\beta = 10$, $m_{1/2} = 300$ GeV, $m_0 = 100$ GeV and $A_0 = 0$. The shadings and lines are as follows. The dark shaded regions have a charged sfermion lighter than the neutralino, so these regions are excluded. Next to this regions at large $|\mu|$ are bands with light shading which have sneutrino LSP. The $b \to s\gamma$ exclusion is presented by the medium shaded regions. The light shaded areas are the cosmologically preferred regions with $0.1 \le \Omega_\chi h^2 \le 0.3$. Also shown along this region, shaded darkest, is the narrower range $0.094 \le \Omega_\chi h^2 \le 0.129$ from WMAP [4]. The $\mu > 0$ region is shaded to indicate that it satisfies the current 2σ range of muon anomalous magnetic moment, $11.5 \times 10^{-10} < \delta a_\mu < 56.3 \times 10^{-10}$. The dot-dashed line is the contour $m_h = 114$ GeV. Regions on the left of this line are excluded. The near-vertical dashed lines are the contour $m_{\chi^\pm} = 103.5$ GeV. Small $|\mu|$ region is excluded. The GUT stability constraint is presented by the dark dot-dashed lines. Only the central region is allowed by this constraint. The near-horizontal solid lines at $m_A \sim 240$ GeV are for the heavy Higgs pole, $2m_\chi = m_A$. The CMSSM cases are presented by the crosses, one for each sign of μ. We see that the NUHM allowed regions are much broader than the CMSSM ones, with $\chi - \widetilde{\nu}$ coannihilation regions at large $|\mu|$ and bino-higgsino transition regions at small $|\mu|$. The GUT stability constraint, in this case, excludes most of the $\chi - \widetilde{\nu}$ coannihilation regions.

In Fig. 2, we fix $m_A = 200$ GeV and plot the mass spectrum as functions of μ. We see that for small $|\mu|$ we have higgsino χ, which is degenerate with the lightest chargino. Sneutrino LSP region is found at large $|\mu|$, while $\widetilde{\tau}$ LSP has relatively small $|\mu|$.

4 Dark Matter Direct Detection Rates

We calculate the neutralino-proton elastic scattering cross section, both spin dependent and spin independent parts. We cover the parameter space by random scan and apply cuts from the experimental constraints. The results for all $\tan\beta$ are shown in Fig. 3. The light shaded regions are what we get if we include constraint from a_μ. We find the range $10^{-10}\,\mathrm{pb} \lesssim \sigma_{SI} \lesssim 10^{-6}\,\mathrm{pb}$ and $\sigma_{SD} \lesssim 10^{-3}$ pb. Compared with the CMSSM, the NUHM elastic scattering could be up to two orders of magnitude large for similar neutralino masses.

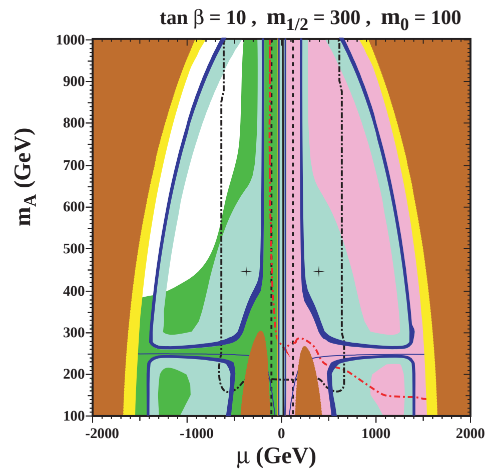

Figure 1. A $\mu - m_A$ plane in the NUHM model for $\tan\beta = 10$, $m_{1/2} = 300$ GeV, $m_0 = 100$ GeV and $A_0 = 0$.

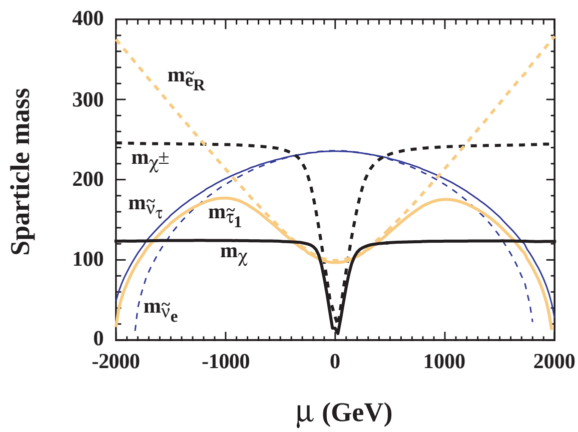

Figure 2. Sparticle mass spectrum as functions of μ for $\tan\beta = 10$, $m_{1/2} = 300$ GeV, $m_0 = 100$ GeV, $A_0 = 0$ and $m_A = 200$ GeV.

5 Conclusion

Relaxing scalar mass universality for the Higgs sector gives us richer phenomenology compared to the CMSSM. There are direct effects on the sfermion mass spectrum through RGE evolution. For example, here sneutrinos could be degenerate with the neutralino LSP. The NUHM cosmological region consists of the bulk, the H & A pole rapid annihilation, the $\chi - \ell$ coannihilation,

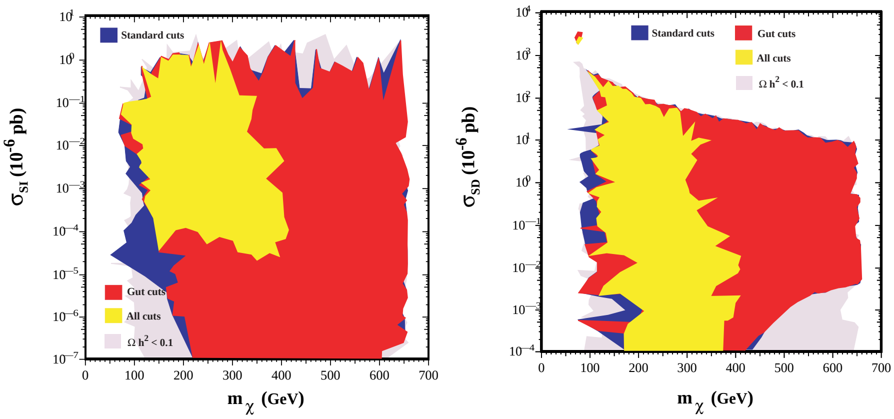

Figure 3. Ranges of spin independent (scalar) and spin dependent cross section in the NUHM model.

the $\chi - \widetilde{\nu}$ coannihilation and the Bino-Higgsino transition regions. (And also $\chi - \widetilde{t}$ coannihilation region for $|A_0| \neq 0$ and large.) Bino-like LSP is still preferred. Mostly Higgsino-like LSP region is excluded either by the LEP constraints or because $\chi - \chi' - \chi^{\pm}$ coannihilation over-annihilates the relic density. Note, however, that the second exclusion is based on the assumption that dark matter consists only of neutralino LSP.

Acknowledgments

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