Higgsino Dark Matter in Nonuniversal Gaugino Mass Models

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Abstract

We study two simple and well motivated nonuniversal gaugino mass models, which predict higgsino dark matter. One can account for the observed dark matter relic density along with the observed Higgs boson mass of \(\simeq 125\) GeV over a large region of the parameter space of each model, corresponding to higgsino mass of \(\simeq 1\) TeV. In each case this parameter region covers the gluino mass range of 2-3 TeV, parts of which can be probed by the 14 TeV LHC experiments. We study these model predictions for LHC in brief and for dark matter detection experiments in greater detail.
1 Introduction

Supersymmetry, in particular the Minimal Supersymmetric Standard Model (MSSM) [1,3] offers a natural candidate for the dark matter [4,5] of the universe in the form of the lightest supersymmetric particle (LSP). Astrophysical constraints require it to be a colourless and neutral particle, while direct detection experiments disfavour a sneutrino dark matter [6]. Thus the favoured dark matter (DM) candidate in the MSSM is the lightest neutralino \( \tilde{\chi}^0_1 \) which could be any combination of the neutral gauginos like bino (\( \tilde{B} \)), wino (\( \tilde{W} \)) and higgsinos \( \tilde{H}_D, \tilde{H}_U \) i.e.

\[
\tilde{\chi}^0_1 = N_{11} \tilde{B} + N_{12} \tilde{W} + N_{13} \tilde{H}_D + N_{14} \tilde{H}_U.
\] (1)

Here \( N_{ij} \) for \( i,j = 1 - 4 \) refers to elements of the matrix that diagonalizes the neutralino mass matrix [3].

In the simplest version of this model, called the constrained MSSM (CMSSM) or the minimal Supergravity (mSUGRA) model [3,7], the lightest neutralino as a dark matter candidate [4,5] is dominantly a bino over most of the parameter space. Since a bino does not carry any gauge charge, its main annihilation mechanism is the so called bulk annihilation process via sfermion exchange. But the Higgs boson mass bound of 114 GeV from LEP [8] implied large sfermion masses in this model [9], which is much reinforced now with discovery of Higgs boson at the LHC with a mass of about 125 GeV [10]. This implies a very inefficient bulk annihilation process, resulting in an overabundance of dark matter relic density over most of the parameter space. We shall see below that there are only a few strips of parameter space available in CMSSM giving cosmologically compatible dark matter relic density i.e. the stau coannihilation, the resonant annihilation, the focus point and the higgsino dark matter regions [11,3] - each of which requires some amount of fine-tuning between SUSY parameters. Moreover, large parts of the stau coannihilation and the resonant annihilation regions are disfavoured by the Higgs boson mass of about 125 GeV, while most of the hyperbolic branch [12,11]/focus point [13] region is disfavoured by the recent direct dark matter detection experiments [14]. While the higgsino dark matter region is unaffected by
these results, it corresponds to squark and gluino masses $\gtrsim 8$-10 TeV in this model, which cannot be probed at the LHC [14,15]. Therefore this region has little practical interest at least for LHC experiments.

In this work we shall study the phenomenology of higgsino dark matter in some simple and predictive nonuniversal gaugino mass (NUGM) models based on SU(5) grand unified theory (GUT) [16–24]. The gaugino mass term in the GUT scale Lagrangian is bilinear in the gaugino fields, which belongs to the adjoint representation of the GUT group. Thus for the 24 dimensional representation of SU(5) the above must transform like one of the representations occurring in their symmetric product [22]:

$$(24 \times 24)_{\text{symm}} = 1 + 24 + 75 + 200.$$  (2)

The mSUGRA model considers the singlet representation for the gaugino mass term, implying a universal gaugino mass at the GUT scale. On the other hand, any of the three nonsinglet representations implies nonuniversal gaugino masses at the same scale. Each of these three NUGM models is as predictive as the CMSSM. We shall see below that the 24 model predicts a bino dominated dark matter as in the case of the CMSSM. But the 75 and the 200 models predict higgsino dominated dark matter over the bulk of their parameter spaces. Thus one can obtain the right amount of dark matter relic density by considering a higgsino mass of $\sim 1$ TeV [11,24]. Unlike the CMSSM, however, this is achieved here naturally with a significantly reduced degree of fine-tuning between SUSY parameters [25]. Moreover, for both these NUGM models, the cosmologically compatible relic density regions of higgsino dark matter correspond to gluino mass range of 2-3 TeV, at least a part of which can be probed by the 14 TeV LHC experiments. Therefore these nonuniversal gaugino mass models should be of great phenomenological interest in the near future.

Section 2 gives a brief overview of the above mentioned universal and nonuniversal gaugino mass models. Section 3 summarizes the phenomenology of the dark matter relic density compatible regions of the CMSSM. Section 4 describes the dark matter relic density compatible regions of the 75 model along with the Higgs boson mass constraint. It lists the SUSY

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1 or a linear combination of them
mass spectra for a set of benchmark points satisfying these constraints, which are expected to be within the reach of the 14 TeV LHC experiments. It also shows the size of the gluino pair production cross-section for these points at the 14 TeV LHC and briefly discusses the signal characteristics. Then it compares the predictions of this model for various direct and indirect dark matter detection experiments. Section 5 gives the analogous description for the 200 model. We conclude with a summary of our results in Section 6.

2 Nonuniversality of Gaugino Masses in SU(5) GUT

The gauge kinetic function that relates to the gaugino masses at the GUT scale originates from the vacuum expectation value of the F-term of a chiral superfield $\Phi$ which causes SUSY breaking. Thus the gaugino masses are obtained via a non-renormalizable dimension-5 operator as given below \[^2\]

$$L \supset \frac{<F_\Phi>_{ij}}{M_{Planck}} \lambda_i \lambda_j.$$  \hspace{1cm} (3)

Here $\lambda_{1,2,3}$ are the U(1), SU(2) and SU(3) gaugino fields bino, wino and gluino respectively. Since gauginos belong to the adjoint representation of the GUT group, $\Phi$ and $F_\Phi$ can belong to any of the irreducible representations occurring in their symmetric product (Eq. 2), i.e. 1, 24, 75 or 200. Thus the unification scale gaugino masses for a given representation $n$ of the SUSY breaking superfield are determined in terms of one mass parameter $m_{1/2}^n$ as

$$M_{1,2,3}^G = C_{1,2,3}^n m_{1/2}^n,$$  \hspace{1cm} (4)

where the values of the coefficients $C_{1,2,3}^n$ are listed in Table I \[^1\]. The coefficients $C_3^n$ are conventionally normalized to 1.

The CMSSM assumes the SUSY breaking superfield $\Phi$ to be a singlet, implying universal gaugino masses at the GUT scale. On the other hand, any of the three nonsinglet representations of $\Phi$ would imply nonuniversal gaugino masses as per Table I. These nonuniversal gaugino mass models can be consistent with the universality of gauge couplings $^2$ $\alpha_G \simeq 1/25$.

\[^2\text{See Ref. \cite{18} and references therein.}\]
and their phenomenology have been widely studied [16–24]. The superparticle masses at the electroweak scale are related to these GUT scale gaugino masses along with the universal scalar mass parameter $m_0$ and trilinear coupling parameter $A_0$, via renormalization group equations (RGE). In particular, the gaugino masses evolve like the corresponding gauge couplings at the one-loop level of the RGE, implying

$$M_1 = (\alpha_1/\alpha_G)M_1^G \simeq (25/60)C_1^n m_1^{n/2},$$

$$M_2 = (\alpha_2/\alpha_G)M_2^G \simeq (25/30)C_2^n m_1^{n/2},$$

$$M_3 = (\alpha_3/\alpha_G)M_3^G \simeq (25/9)C_3^n m_1^{n/2}. \quad (5)$$

The corresponding higgsino mass $\mu$ is obtained from the electroweak symmetry breaking condition along with the RGE for the Higgs scalar masses. Neglecting contributions from the trilinear soft terms, one has a relatively simple expression for the higgsino mass at the one-loop level of the RGE [26], i.e.

$$\mu^2 + \frac{1}{2}M_2^h \simeq -0.1m_0^2 + 2.1M_3^{G^2} - 0.22M_2^{G^2} - 0.006M_1^{G^2} + 0.006M_1^G M_2^G + 0.19M_2^G M_3^G + 0.03M_1^G M_3^G, \quad (6)$$

where the numerical coefficients on the right hand side correspond to a representative value of $\tan \beta = 10$, but have only modest variations over the moderate $\tan \beta$ region.

Our results are based on exact numerical solutions of the two-loop RGEs including also the contributions from the trilinear couplings using the SuSpect code [27]. Nonetheless, the

| n  | $C_3^n$ | $C_2^n$ | $C_1^n$ |
|----|--------|--------|--------|
| 1  | 1      | 1      | 1      |
| 24 | 1      | -3/2   | -1/2   |
| 75 | 1      | 3      | -5     |
| 200| 1      | 2      | 10     |

**Table 1:** Coefficient $C_{1,2,3}^n$ for the unification scale gaugino mass parameters for each representation.
approximate formulae of Eq. (5) and Eq. (6) are very useful in understanding the composition of the LSP dark matter in these models. The dominant contribution to the mass of higgsino \( \mu \) comes from the \( M_3^2 \) term, implying \( \mu \sim \sqrt{2} m_{1/2} \) from Table 1 for all the four models. On the other hand, for the mass of bino, Eq.(5) shows that \( M_1 \sim 0.4 m_{1/2} \) for CMSSM, implying a bino dominated LSP dark matter in this model. One sees from Table [1] that \( M_1 \) is further suppressed by a factor of half in the 24 model, implying an even more strongly bino dominated LSP dark matter. Thus one obtains a generic overabundance of dark matter in the CMSSM as well as in the 24 model. For the 75 and the 200 models, however, one sees from Table [1] that the bino mass \( M_1 \) is enhanced by factors 5 and 10 respectively relative to the CMSSM, implying a higgsino dominated LSP dark matter in these nonuniversal gaugino mass models. Since higgsino has an efficient annihilation mechanism via its isospin gauge coupling to W-boson, one obtains cosmologically compatible dark matter relic density in these models and this corresponds to a higgsino mass \( \mu \simeq 1 \text{ TeV} \) [11,24].

3 Cosmologically Compatible Dark Matter Relic Density Regions of CMSSM

The cosmologically compatible dark matter relic density regions of the CMSSM have been thoroughly investigated over last two years in the light of the 125 GeV Higgs boson mass and other LHC results along with taking into account the constraints from the direct detection of dark matter experiments [14,15]. We shall briefly revisit this issue here as a prelude to our investigation of higgsino dark matter in nonuniversal gaugino mass models. This will provide a very useful backdrop for comparing the relative advantage of the dark matter scenario in the latter models. We have used the SuSpect [27] code in our computation that uses two-loop RGEs and radiative electroweak symmetry breaking (REWSB) to generate the electroweak scale SUSY spectra. We consider a theoretical uncertainty of around 3 GeV in lightest Higgs scalar mass \( m_h \) within MSSM. This arises due to EWSB scale dependence, renormalization scheme such as the \( \overline{\text{DR}} \) or the on-shell schemes as used in SuSpect and
Feynhiggs \cite{28} respectively, uncertainties in the mass of top quark and higher order loop correction up to 3 loops \cite{29}. Hence, we consider a mass of 122 GeV should be consistent with the Higgs data.

![Figure 1](image)

**Figure 1:** The CMSSM/mSUGRA parameter space for representative values of moderate $\tan \beta = 10$ (left) and large $\tan \beta = 50$ (right). The cosmologically compatible dark matter relic density regions are indicated by the red dots, while the constraints from the Higgs boson mass band of 122-125 GeV are indicated by the blue solid lines. The constraints from $B_s \to \mu^+\mu^-$ and $b \to s\gamma$ decays are also indicated by solid magenta and maroon dashed lines respectively (see text). The region above these lines are allowed by the corresponding constraints. The green region at the top is mostly excluded due to absence of REWSB ($\mu^2 < 0$), while the green region at the bottom is excluded because of stau turning to be the LSP.

Fig.1 shows the CMSSM parameter space for representative values of moderate $\tan \beta$ (= 10, Fig.1(a)) and large $\tan \beta$ (= 50, Fig.1(b)). The shaded region on top is disallowed because of no REWSB ($\mu^2 < 0$), while the bottom strip is disallowed because of stau turning to become the LSP. The constraints from the Higgs boson mass band of 122-125 GeV are indicated by the blue solid lines. Note that one requires a fairly large value of the GUT scale trilinear coupling parameter, $A_0 = -2$ TeV, consistent with the charge and color breaking
constraint \[30\] to raise the Higgs mass above 122 GeV via the stop mixing contribution at \(\tan \beta = 10\). The constraints from the \(B_s \to \mu^+\mu^- (2\sigma)\) \[31\] \[34\] and \(b \to s\gamma (3\sigma)\) \[35\] \[36\] decays are also indicated.

\[
2.77 \times 10^{-4} < Br(b \to s\gamma) < 4.09 \times 10^{-4},
\]
\[
0.67 \times 10^{-9} < Br(B_s \to \mu^+\mu^-) < 6.22 \times 10^{-9}.
\] (7)

The strips of red dots indicate the cosmologically compatible dark matter relic density regions, satisfying WMAP \[37\]/PLANCK \[38\] data:\[3\]

\[
0.09 < \Omega h^2 < 0.14.
\] (8)

They are usually classified into the following four regions:\[4\]

1. Stau coannihilation region is the short strip adjacent to the lower boundary in the Fig.1(a) where the LSP dark matter co-annihilates with a nearly degenerate stau, \(\tilde{\chi}_1^0 \tilde{\tau}_1 \to \tau \gamma (Z)\) via s-channel \(\tau\) or t-channel \(\tilde{\tau}\) exchange. It requires a degeneracy between the bino dark matter and the stau masses to within 10-15 %.

2. The resonant annihilation region is the funnel shaped strip in Fig.1(b) corresponding to s-channel annihilation of the dark matter pair into a fermion pair \(\tilde{\chi}_1^0 \tilde{\chi}_1^0 \to f \bar{f}\) principally via the pseudoscalar Higgs boson \(A\).

Since the \(H\tilde{\chi}_1^0 \tilde{\chi}_1^0\) and \(A\tilde{\chi}_1^0 \tilde{\chi}_1^0\) couplings are proportional to the product of the gaugino and higgsino components of \(\tilde{\chi}_1^0\) the same are strongly suppressed for a bino dominated LSP. Therefore it requires resonance condition, \(M_A \simeq 2M_1\), for enhancement from the Breit-Wigner denominator along with a large \(\tan \beta\) for a large coupling of \(A\) to the fermion pair.

Note that both the stau coannihilation and resonant annihilation regions require some fine-tuning between independent SUSY mass parameters. Besides, large parts of both regions are disfavoured by the Higgs boson mass constraint.

\[3\]The limits correspond to a 5\(\sigma\) range of the PLANCK data that accommodates well the WMAP provided range.

\[4\]We will ignore here the so called bulk-annihilation region characterized by LSP pair annihilation via t-channel slepton exchange since it occurs for smaller \(m_{1/2}\) zone that is excluded by the Higgs mass data.
3. The hyperbolic branch/focus point region near the upper boundary in each parts of
Fig.1 extends up to $m_{1/2} \simeq 3$ TeV. Here the LSP has a large admixture of bino and higgsino
components because $\mu \sim M_1$. Since the $Z\tilde{\chi}^0_1\tilde{\chi}^0_1$ coupling is proportional to the difference
of the squares of the higgsino components of $\tilde{\chi}^0_1$ (i.e. $N_{13}^2 - N_{14}^2$), the pair annihilation
$\tilde{\chi}^0_1\tilde{\chi}^0_1 \rightarrow f\bar{f}$ occurs mainly via Z boson exchange.

Rewriting the electroweak symmetry breaking condition (Eq.6) for the CMSSM in terms
of $m_0$ and $m_{1/2}$ one obtains the hyperbolic equation in $m_{1/2}$ and $m_0$ for fixed values of $\mu$,

$$\mu^2 + 1/2 M_Z^2 \simeq -0.1 m_0^2 + 2 m_{1/2}^2.$$  (9)

One can have substantial cancellation between the two terms on the right hand side,
within the hyperbolic branch/focus point region with $m_0 >> m_{1/2}$. This ensures a low value
of $\mu \sim M_1 \sim 0.4m_{1/2}$. Note however that it implies significant amount of fine-tuning between
$m_0$ and $m_{1/2}$. Moreover, most of this region is strongly disfavoured by the negative results
from the recent direct detection of DM experiments [14]. The reason is that sizable gaugino
and higgsino components of $\tilde{\chi}^0_1$ in this region implies large $H\tilde{\chi}^0_1\tilde{\chi}^0_1$ coupling, predicting large
spin-independent (SI) $\tilde{\chi}^0_1 p$ cross-sections for these experiments.

4. Finally, the right end of the strip near the upper boundary corresponds to $\mu \lesssim M_1$, i.e.
$\mu \lesssim 0.4m_{1/2}$, implying a higgsino dominated dark matter in CMSSM [11]. Since the higgsino
pair can annihilate via their gauge coupling to W bosons, one obtains the desired dark matter relic density (Eq.8) for a higgsino DM mass $\mu \simeq 1$ TeV, practically independent of any other
SUSY parameter. The higgsino DM region is realized for $m_{1/2} \gtrsim 3$ TeV so that the mass
of bino $M_1 \gtrsim 1.2$ TeV (Eq.5) while the mass of corresponding gluino is above 10 TeV. The
squark masses are also sufficiently heavy which imply that the strongly interacting sparticles
to be well beyond the reach of LHC at 14 TeV. The TeV scale superparticle masses can
nevertheless easily account for the desired Higgs boson mass of $\sim 125$ GeV. However, one
sees from the above hyperbolic equation (Eq. 9) that in this case there is at least as large a
fine-tuning between $m_0$ and $m_{1/2}$ parameters as in the focus point region. We note that the
1 TeV higgsino signal can be detected via the associated single photon process at the 3 TeV
CLIC [24,39]. But it is generally believed that there will be no CLIC if there is no SUSY
signal at the LHC. In that sense this region seems to be of little practical interest at least for the colliders.

We shall see below that one obtains a higgsino LSP dark matter of mass 1 TeV in the 75 and 200 models with many properties similar to those of CMSSM, but with two major advantages. It occurs naturally in these nonuniversal gaugino mass models, without requiring any large cancellation between independent SUSY parameters. Moreover, the corresponding gluino and top squark masses lie over the 2-3 TeV region, at least a part of which are within the reach of 14 TeV LHC.

4 Phenomenology of Higgsino Dark Matter in the 75 Model

Fig. 2 shows the $m_{1/2} - m_0$ parameter plane of the NUGM model corresponding to the representation 75 of SU(5) GUT for representative values of $\tan \beta = 10$ and 30 when $A_0 = -3$ TeV. The green region I at the top is excluded due to non-convergent EWSB solution, while II at the bottom is excluded due to the lighter stop ($\tilde{t}_1$) being the LSP/tachyonic for both Fig.2(a) and Fig.2(b). The cosmological relic density satisfying region of the higgsino dark matter is indicated by the red dots, while the constraints from the Higgs boson mass range of 122-125 GeV are indicated by the blue solid lines. Contours of gluino and lighter stop masses are indicated along with the $\mu = 1$ TeV contour. In the band DEF the cosmological relic density of dark matter is achieved through co-annihilation among the degenerate charged and neutral higgsinos ($\tilde{\chi}_1^0, \tilde{\chi}_2^0, \tilde{\chi}_1^\pm$), while in the strip ABC near the lower boundary there is additional co-annihilation with the lighter stop ($\tilde{t}_1$). In the regions III and IV we obtain underabundant and overabundant DM respectively for Fig.2(a), whereas the regions labelled with III and IV correspond to only underabundant DM in Fig.2(b). $B_s \rightarrow \mu^+ \mu^-$ and $b \rightarrow s\gamma$ constraints are satisfied everywhere. We now comment on the appearance of the clip regions in both of the above figures. We have investigated it by varying $m_0$ for a given $m_{1/2}$ in relevant regions. There appears a jump in $\mu$ near a particular zone of $m_0$ associated with
the *clip* region. This is essentially associated with the way the corrections to $\mu^2$ arising out of a finite order effective potential (one or two loop) are computed [40]. It is possible that a logarithmic term for the correction (typically from the top-squark contribution) may turn from a negative value to a positive value almost discontinuously for a small change in $m_0$ around a given value of $m_0$. This would give rise a jump in the value of $\mu$. For a higgsino dominated LSP such abrupt, albeit small change in $\mu$ may mean a significant amount of change in the relic density ($\sim \mu^2$). Thus the above explains the appearance of *clip* regions within the relic density satisfied zone. Similar effect occurs in the zone near the REWSB boundary. Of course inclusion of higher order terms in the effective potential would smoothen out such jumps or eliminate the *clip* regions in general.

Table 2 lists the superparticle masses for three benchmark points from the left part of each figure namely Fig.2(a) and Fig.2(b) with relatively light gluinos, which can be probed at the high luminosity run of the 14 TeV LHC. The last row shows the gluino pair-production cross-section for these points at the 14 TeV LHC as obtained by using the code Prospino [41]. These cross-sections correspond to several hundred gluino pairs at 100 fb$^{-1}$ which can be probed in the high luminosity run of LHC. Moreover, the probe can be extended up to a gluino mass of 2.5 TeV at the very high luminosity runs of 1000-3000 fb$^{-1}$ [42]. We note that Table 2 shows an inverted hierarchy of squark masses with a relatively light stop $\tilde{t}_1$. Together with the large coupling of stop with higgsino, it implies that the gluino will dominantly decay via a real or virtual stop: $\tilde{g} \rightarrow t\tilde{\chi}_1^{0,2}$.

Thus one expects a distinctive signal with four top quarks along with a large missing $E_T$ from the gluino pair decay. We hope the members of the ATLAS and CMS collaborations will make detailed simulation studies of this signal, which is beyond the scope of the present work. We shall proceed now to the model predictions for the direct and indirect dark matter detection experiments.

The spin-independent scattering cross section $\sigma_{p\tilde{\chi}_1^0}^{SI}$ of nucleon with $\tilde{\chi}_1^0$ involves Higgs exchange (t-channel) or squark exchange (s-channel) diagrams. With the present LHC limit of squark masses, the Higgs exchange processes dominate in $\sigma_{p\tilde{\chi}_1^0}^{SI}$. Typically, unless LSP
**Figure 2:** (a): Plot in the $m_0 - m_{1/2}$ plane for 75 model for $\tan\beta = 10$. Region I is excluded because of nonconvergent EWSB solution. Region II is disfavored as stop becomes the LSP or tachyonic there. Contours for stop, gluino masses, $\mu = 1$ TeV, $m_h = 125$ GeV and $m_h = 122$ GeV are also shown. Red points satisfy the relic density constraint (Eq.8). For the red points lying along the boundary of Region II in the strip ABC, the LSP is higgsino like. Along the strip DEF also we find the LSP to be higgsino like. In the region ABC the main DM annihilating mechanisms are coannihilations involving $\tilde{t}_1, \tilde{\chi}^\pm_1, \tilde{\chi}^0_1$ and $\tilde{\chi}^0_2$. All the way along the strip DEF coannihilations occur where $\tilde{\chi}^\pm_1, \tilde{\chi}^0_1$ and $\tilde{\chi}^0_2$ take part almost equally. In Regions III and IV we obtain underabundant and overabundant DM respectively. The entire parameter space is allowed by $B_s \to \mu^+\mu^-$ and $b \to s\gamma$ constraints. (b): Similar plot as (a) with $\tan\beta = 30$. Colours and conventions are same as plot (a). Here we get underabundant DM for both the Regions III and IV.

is a mixture of higgsino with bino or wino the couplings are suppressed. For a higgsino-dominated scenario of LSP with $\tilde{\chi}^0_1 (|\mu| << M_1, M_2)$ and for the decoupling limit of Higgs boson ($M_2^2 << M_A^2$) one finds the following relevant couplings \cite{43} $C_{h\tilde{\chi}^0\tilde{\chi}^0}$ and $C_{Hz\tilde{\chi}^0\tilde{\chi}^0}$ that explicitly show the suppression effect when $M_1$ and $M_2$ are away from $\mu$. The results are not however valid when $|\mu|$ is close to either of $M_1$ and $M_2$.

$$C_{h\tilde{\chi}^0\tilde{\chi}^0} \simeq \mp \frac{1}{2} M_Z e W [1 \pm \sin 2\beta] \left[ \frac{t_W^2}{M_1 - |\mu|} + \frac{1}{M_2 - |\mu|} \right],$$
Table 2: Spectra of six benchmark points for the 75 model. Masses and mass parameters are shown in GeV. Gluino pair production cross sections correspond to a 14 TeV LHC run. The relevant SM parameters used are $m_t^{pole} = 173.5$ GeV, $m_{\chi_0}^{MS} = 4.18$ GeV and $m_\tau = 1.77$ GeV.

$$C_{H\tilde{t}\tilde{t}} \simeq \frac{1}{2} M_Z c_W \cos 2\beta \left[ \frac{t_{1W}^2}{M_1 - |\mu|} + \frac{1}{M_2 - |\mu|} \right],$$

for $\mu > 0$ and $\mu < 0$ respectively with $s_W = \sin \theta_W$ etc. The particular result to note from the above equation for the higgsino dominated LSP case is that the direct detection SI cross-section decreases with increase in gaugino masses $M_1$ and $M_2$. Thus for a given $m_{1/2}$, the 75 model will have a decreased value for $\sigma_{SI}^{\tilde{t}\tilde{t}}$ because of larger values of masses of bino and wino when compared with the mSUGRA scenario. Fig 3(a) and Fig 3(b) show the results of $\sigma_{SI}^{\tilde{t}\tilde{t}}$ for different values of the mass of the LSP for $\tan \beta = 10$ and $\tan \beta = 30$. This corresponds to the parameter space of Fig 2. The exclusion contours from XENON100 [44] and LUX [45] are also shown in addition to the estimated exclusion level for future XENON1T [46]. The relic density satisfied regions bracketed within $900 < m_{\chi_0} < 1300$ GeV for $\tan \beta = 10$ and $900 < m_{\chi_0} < 1200$ GeV for $\tan \beta = 30$ are shown in red and the points generally satisfy the LUX limit. On the other hand a large region of parameter space may be probed via the
future experiment of XENON1T.

Figure 3: (a) Spin independent scattering cross-section of LSP with proton as a function of LSP mass for the 75 model with $\tan\beta = 10$. The constraints coming from direct detection experiments like XENON100, LUX and the expected limit from XENON1T are shown. The points in red satisfy the relic density constraint. (b) Similar plot as (a) for $\tan\beta = 30$.

Coming to the spin-dependent LSP-proton cross section we note that $\sigma^{SD}_{p\chi}$ is associated with a Z-exchange since the large values of squark masses after the LHC data would not cause any significant contribution from squark exchange diagrams. The coupling of $\tilde{\chi}_1^0 \tilde{\chi}_1^0 Z$ related to a higgsino asymmetry is given by $C^Z_{\tilde{\chi}_1^0 \tilde{\chi}_1^0} = |N^2_{13} - N^2_{14}|$. For a higgsino-like LSP one can have the following approximate expression $^{43,47}$:

$$C^Z_{\tilde{\chi}_1^0 \tilde{\chi}_1^0} \simeq \frac{1}{2} \left[ t_W^2 \frac{M_W^2}{M_1\mu} + \frac{M_Z^2}{M_2\mu} \right] \cos 2\beta + \mathcal{O}(\frac{\mu}{M_1}, \frac{\mu}{M_2}),$$  \hspace{1cm} (11)

for $\mu > 0$ and $\mu < 0$ respectively. We note that for the relic density satisfied region of parameter space, a higgsino dominated LSP when associated with sufficiently large electroweak gaugino masses (which is indeed true for both the NUGM models considered in this work) results into a significant amount of suppression of $\sigma^{SD}_{p\chi}$. This is visible in Fig.4(a) as well as in Fig.4(b), the scatter plots of $\sigma^{SD}_{p\chi}$ vs $m_{\tilde{\chi}_1^0}$ for $\tan\beta = 10$ and 30 respectively for the 75 model. For the relic density satisfied zones of $m_{\tilde{\chi}_1^0}$, $\sigma^{SD}_{p\chi}$ (as shown in red dots) is way too small to be
probed via the shown IceCube exclusion limits (both the existing and the projected limits). Here, the spin-dependent cross section is obtained via indirect means of searching for muon neutrinos at IceCube [48] arising out of dark matter annihilation within the Sun. We will also discuss the muon flux limit in relation to the mass of dark matter in this section. We may mention that in the present scenario, the IceCube limits are stronger [49, 50] than the dedicated spin-dependent direct detection experiments like COUPP [51].

**Figure 4:** Variation of spin dependent cross section with the LSP mass for the 75 model with \( \tan \beta = 10 \). IceCube exclusion limit for the \( \tilde{\chi}_1^0 \tilde{\chi}_1^0 \rightarrow W^+ W^- \) channel is shown as a green line [49]. The blue line represents the expected sensitivity reach of IceCube. (b) Similar plot as (a) for \( \tan \beta = 30 \).

We next consider DM indirect detection studies for the 75 model for photon signal. There can be a sufficient degree of gravitational capture of weakly interacting massive particles (WIMP) due to nuclear scattering effects. Gravitational capture may occur in the dense regions like galactic centers, dwarf galaxies or in the core regions of objects within the solar system such as the Sun or the Earth [4, 5]. The LSP pair-annihilation would produce fermion-antifermion pairs or electroweak gauge bosons. Decays of products of primary annihilation and hadronization may produce \( \pi^0 \) that would eventually produce photons. Apart from the above there can be final state radiation effects (FSR) of primarily produced particles. We
note that the environment of gravitational capture and LSP annihilation is associated with a much smaller velocity \((v/c \sim 10^{-3})\) unlike a much larger velocity existing at the time of freeze-out. Thus, the annihilation of LSPs in the present day scenario involves a large \(p\)-wave suppression \([(v/c)^2]\). We remind ourselves that LSP being a Majorana particle the combined CP-property and the combined parity of the LSP-pair are the same. This makes the favored \(s\)-channel particle namely the CP-odd Higgs boson \(A\) to contribute dominantly toward the photon signal which on the other hand is \(p\)-wave suppressed as discussed above. We note that a larger higgsino content is generally favourable for photon signal. However, NUGM models under discussion depend on high scale input parameters and involve RGEs and REWSB that lead to correlated SUSY spectra. All these cause an \(s\)-channel Higgs resonance to become a remote possibility. Figs.5(a) and 5(b) show \(<\sigma v>\), the thermally averaged LSP-pair annihilation cross-section as a function of \(m_{\tilde{\chi}^0_1}\) for the 75 model with \(\tan \beta =10\) and \(\tan \beta =30\) respectively. Fermi-LAT constraint from LAT dwarf spheroidal stacking (4 years) \([52]\) is shown as a green line. The red points correspond to relic density satisfied parameter points. Owing to larger \(b\bar{b}\) coupling of Higgs for a large \(\tan \beta\), \(<\sigma v>\) is generally larger in Fig.5(b) in comparison with Fig.5(a). The parameter space for the 75 model is practically unconstrained by the present Fermi limit.

We would like to discuss briefly about probing higgsino dominated dark matter via indirect detection of muon flux at IceCube \([48]\) due to neutrinos from the Sun. In SUSY models neutrinos cannot be produced at tree level of neutralino annihilations. However, neutrinos may arise from sources like heavy quarks, gauge bosons, tau leptons etc\(^5\). Thus neutrinos are produced with a broad energy distributions with energy reaching upto a sizable fraction of the DM mass. For DM mass less than \(M_W\), neutrinos from \(b\bar{b}\) or \(\tau^+\tau^-\) are the primary channels. But these are not very promising candidates of detection with given experimental thresholds of neutrino detection. For massive neutralinos, annihilations may additionally lead to gauge bosons, top quarks or Higgs bosons. A neutralino with a substantial higgsino

\(^5\)There can be possibilities of having neutrinos from two-to-two annihilation into gauge bosons via loops \([53]\)
Figure 5: (a) DM self annihilation cross-section as a function of DM mass for the 75 model with $\tan \beta = 10$. Fermi-LAT constraint [LAT dwarf spheroidal stacking (4 years)] is shown as a green line. The parameter space is practically unconstrained by Fermi data. (b) Similar plot as (a) for $\tan \beta = 30$.

Component may undergo pair annihilation to produce gauge bosons which in turn may produce high energy neutrinos. We must keep in mind that neutrinos of energy several hundreds of GeV produced inside the Sun would be depleted since the probability of a neutrino to escape the Sun without interaction is given by $P = e^{-E_\nu/E_k}$ where $E_k$ specific to the types of neutrino ranges from 130 to 230 GeV. Neutrino oscillation is taken into account while computing the flux of muon neutrinos at the detector. At the detector muon flux are detected that arise from neutrinos via charge-current interactions.

Neutrino signals from the Sun or a dense region of galaxy in general involves capture and annihilation of WIMPs. In general both spin-independent and spin-dependent types of scattering of WIMPs with various nuclei may lead to appreciable reduction of energy leading to WIMP velocity to go below the escape velocity. This leads to WIMPs being captured within the object and also undergoing pair annihilations. Thus the time evolution of $N$ WIMPs reads,

$$\frac{dN}{dt} = C - C_A N^2.$$
Here $C$ refers to the rate at which WIMPs are captured and $C_A$ depends on the annihilation cross section of WIMPs and is related to the WIMP annihilation rate $\Gamma_A$ via $\Gamma_A = \frac{1}{2}C_A N^2$ in the Sun $[5, 54, 55]$. Any possibility to have a positive evaporation term that is linear in $N$ is neglected here. The above arises out of a scenario of WIMP-nuclear scattering where WIMP is much lighter than a given nucleus in abundance in the Sun. Such terms may potentially increase the speed of WIMP above the escape velocity $[56]$. The time-dependence of $N$ from Eq.12 leads to $\Gamma_A \equiv \frac{1}{2}C_A N^2 = \frac{1}{2}C \tanh^2(t/\tau)$ where $\tau = 1/\sqrt{CC_A}$. With appreciably large capture and annihilation rates that indeed is possible for the Sun for various models including Supersymmetry and with the present time $t = t^0 = 4.5 \times 10^9$ years, it is realistic to assume $t/\tau >> 1$ leading to $\Gamma_A = \frac{1}{2}C$. This of course means an equilibrium scenario out of capture and annihilation of WIMPs $[57]$. This is however not true for capture and annihilation of WIMPs in the Earth which is much less massive leading to much smaller escape velocity or it has the dominance of spin-independent interactions in the WIMP-nuclear scattering resulting into reduced capture rates for WIMPs. Thus probing DM via muon flux due to neutrino propagation is not so promising for the Earth when compared to the prospect of the same for the Sun $[5]$. We must note that both SI and SD cross-sections are important for capture of WIMPs in the Sun $[58, 53]$. Capture cross section may be related through suitable models to SI and SD WIMP-nuclear cross sections and it is through such relations measurement of muon flux due to neutrino signal may be translated into setting limits on SI and SD cross sections $[5, 53]$. 

Fig.6(a) and Fig.6(b) show the results of muon flux with respect to the mass of LSP for $\tan \beta = 10$ and 30 respectively for the 75 model. The IceCube exclusion limit for the $\tilde{\chi}_1^0 \tilde{\chi}_1^0 \rightarrow W^+ W^-$ channel is shown as green line $[49]$. The blue line represents the expected sensitivity reach of IceCube. Clearly, IceCube would not be able to probe the region of parameter space that satisfies the relic density limits.
Figure 6: Variation of muon flux with the LSP mass for the 75 model with $\tan\beta = 10$. IceCube exclusion limit for the $\tilde{\chi}_1^0 \tilde{\chi}_1^0 \rightarrow W^+ W^-$ channel is shown as a green line [49]. The blue line represents the expected sensitivity of IceCube. (b) Similar plot as (a) for $\tan\beta = 30$.

5 Phenomenology of Higgsino Dark Matter in the 200 Model

Fig. 7(a) and Fig. 7(b) show the scatter plots in the $m_{\tilde{\chi}_1^0} - m_0$ plane of the NUGM model corresponding to the representation 200 of SU(5) GUT for representative values of $\tan\beta = 10$ and 30 when $A_0 = -2$ TeV. Region I is excluded because of nonconvergent EWSB solution. Region II is disallowed because lighter stop ($\tilde{t}_1$) becomes the LSP or tachyonic. Contours for squark, gluino masses for a few different values along with the contours for $\mu = 1$ TeV, $m_h = 122$ GeV and $m_H = 125$ GeV are also shown. Red points satisfy the relic density constraint. In the region A the LSP is higgsino-like with very little wino admixture. The mechanisms that allow the DM to satisfy the relic density constraint are coannihilation processes among $\tilde{\chi}_1^\pm, \tilde{\chi}_1^0, \tilde{\chi}_2^0$. Along the branches B and C the LSP is also higgsino like. There are coannihilations involving $\tilde{\chi}_1^\pm, \tilde{\chi}_1^0, \tilde{\chi}_2^0$. Here additionally, we find $m_{\tilde{\chi}_1^0} \simeq m_{\tilde{\chi}_1^\pm} \simeq M_A/2$. Thus we find s-channel Higgs ($A, H, H^\pm$) resonance processes involving coannihilations among $\tilde{\chi}_1^0$ and/or $\tilde{\chi}_1^\pm/\tilde{\chi}_2^0$. Along the strips DE and EF we also get mostly
a higgsino like LSP. Here coannihilation processes involving $\tilde{\chi}^\pm_1$, $\tilde{\chi}^0_2$ and $\tilde{\chi}^0_1$ cause the dark matter to achieve the right relic density. For regions III, IV and V we get underabundant DM, whereas regions VI and VII give overabundant DM. The entire parameter space respects $B_s \to \mu^+\mu^-$ and $b \to s\gamma$ constraints.

Table 3 shows the super-partner masses and other data of phenomenological interest for three benchmark points each for $\tan \beta = 10$ and 30 corresponding to Fig 7(a) and Fig 7(b) respectively. The mass patterns are more or less not very different from the 75 model. However, we must keep in mind that $M_1^G$ is significantly larger (by a factor of 2) whereas $M_2^G$ is smaller (by a factor of $\frac{2}{3}$) for the 200 model when compared with the 75 model (see Table 1). Consequently, the masses of left and right components of scalars are affected differently via RGE effects. The change happens such that the almost all the squarks and the sleptons are more split among the left and the right scalars in the 200 model. The stop sector has a reduced splitting because of smaller $|A_0|$ considered here compared to the 75 model. The last row shows the gluino pair-production cross-section (NLO) at the 14 TeV LHC using Prospino [41]. Typically these would correspond to fewer gluino pairs compared to the 75 model. Nonetheless they correspond to around 100 events in the high luminosity 100 fb$^{-1}$ run of LHC.

Fig 8(a) and Fig 8(b) show the scatter plots of the spin-independent direct detection cross section of neutralino dark matter with respect to the mass of LSP in the 200 model for $\tan \beta = 10$ and 30 respectively. The exclusion contours from XENON100 [44] and LUX [45] are also shown in addition to the estimated exclusion level for future XENON1T [46]. The relic density satisfied region $900 < m_{\tilde{\chi}^0_1} < 1400$ GeV for both values of $\tan \beta$ are shown in red and an appreciable number of parameter points are discarded via LUX limit. On the other hand a large region of parameter space may be probed via the future experiment of XENON1T. We note that the 200 model has a smaller wino mass ($M_2$) compared to the same for the 75 model for a given value of $m_{1/2}$. Thus the SI cross-section can be understood to be larger for the 200 model (Eq.10) due to relative closeness of values between $\mu$ and $M_2$.  

\[ \text{Eq.10} \]
Figure 7: (a) Allowed parameter space in the $m_0 - m_{1/2}$ plane for the 200 model for $\tan\beta = 10$. Region I is excluded because of nonconvergent EWSB solution. Region II is disallowed because stop becomes the LSP or tachyonic. Contours for squark, gluino masses, $\mu = 1$ TeV, $m_h = 122$ GeV and $m_h = 125$ GeV are also shown. Red points satisfy the relic density constraint. In the region A the LSP is higgsino-like with very little wino admixture. The mechanisms that allow the DM to satisfy WMAP relic density constraint are coannihilation processes among $\tilde{\chi}_1^\pm$, $\tilde{\chi}^0_1$, $\tilde{\chi}^0_2$. Along the branches B and C the LSP is higgsino like. There are coannihilations involving $\tilde{\chi}_1^\pm$, $\tilde{\chi}^0_1$, $\tilde{\chi}^0_2$. Here, additionally we find $m_{\tilde{\chi}_1^0} \approx m_{\tilde{\chi}_1^\pm} \approx M_A/2$. Thus we find s-channel Higgs ($A, H, H^\pm$) resonance processes involving coannihilations among $\tilde{\chi}^0_1$ and/or $\tilde{\chi}_1^\pm/\tilde{\chi}^0_2$. Along the strips DE and EF we also get mostly a higgsino like LSP and coannihilation among $\tilde{\chi}_1^\pm$, $\tilde{\chi}^0_2$ and $\tilde{\chi}^0_1$ helps the dark matter to achieve the right relic density. For regions III, IV and V we get underabundant DM, whereas regions VI and VII give over-abundant DM. The parameter space is unconstrained by $B_s \to \mu^+ \mu^-$ and $b \to s\gamma$ limits. (b) Similar plot as (a) for $\tan\beta = 30$.

Consequently, a larger region of parameter space in the 200 model is excluded via the LUX limit in comparison with the 75 model (Fig.3).

Fig.9(a) and Fig.9(b) show the scatter plots of $\sigma_{px}^{SD}$ vs $m_{\chi_1^0}$ for $\tan\beta = 10$ and 30 respectively for the 200 model. For the relic density satisfied zones of $m_{\chi_1^0}$, $\sigma_{px}^{SD}$ (as shown
Table 3: Spectra of six benchmark points for the 200 model. Masses and mass parameters are shown in GeV. Gluino pair production cross sections correspond to a 14 TeV LHC run.

| Parameter | 1  | 2  | 3  | 4  | 5  | 6  |
|-----------|----|----|----|----|----|----|
| $m_{1/2}$ | 818.94 | 818.46 | 874.26 | 833.33 | 732.93 | 881.86 |
| $m_0$    | 1663.05 | 2847.18 | 895.64 | 1102.62 | 2587.57 | 644.69 |
| $\tan \beta$ | 10.00 | 10.00 | 10.00 | 30.00 | 30.00 | 30.00 |
| $\Lambda_0$ | -2000.00 | -2000.00 | -2000.00 | -2000.00 | -2000.00 | -2000.00 |
| $(M_1, M_2, M_3)$ | 3781.13, 16179 | 3670.1318, 1695 | 3880.1402, 1842 | 3696.1338, 1763 | 3722.1811, 1534 | 3912.1416, 1865 |
| $\mu$ | 1224.92 | 1224.92 | 1224.92 | 1224.92 | 1224.92 | 1224.92 |
| $\tan \beta$ | 10.00 | 10.00 | 10.00 | 30.00 | 30.00 | 30.00 |
| $(m_{\tilde{L}}, m_{\tilde{R}})$ | 2510.23, 3534.60 | 3364.87, 4134.98 | 2140.52, 3338.13 | 2156.49, 3258.35 | 3047.09, 3394.37 | 2066.61, 3308.62 |
| $m_0$ | 1224.92 | 1224.92 | 1224.92 | 1224.92 | 1224.92 | 1224.92 |
| $\mu$ | 1096.25 | 1096.58 | 1096.80 | 1102.62 | 1110.36 | 1112.80 |
| $\Lambda_0$ | -2000.00 | -2000.00 | -2000.00 | -2000.00 | -2000.00 | -2000.00 |
| $(M_1, M_2, M_3)$ | 3781.13, 16179 | 3670.1318, 1695 | 3880.1402, 1842 | 3696.1338, 1763 | 3722.1811, 1534 | 3912.1416, 1865 |
| $\mu$ | 1224.92 | 1224.92 | 1224.92 | 1224.92 | 1224.92 | 1224.92 |
| $\tan \beta$ | 10.00 | 10.00 | 10.00 | 30.00 | 30.00 | 30.00 |
| $(m_{\tilde{L}}, m_{\tilde{R}})$ | 2510.23, 3534.60 | 3364.87, 4134.98 | 2140.52, 3338.13 | 2156.49, 3258.35 | 3047.09, 3394.37 | 2066.61, 3308.62 |
| $m_0$ | 1224.92 | 1224.92 | 1224.92 | 1224.92 | 1224.92 | 1224.92 |
| $\mu$ | 1096.25 | 1096.58 | 1096.80 | 1102.62 | 1110.36 | 1112.80 |
| $\Lambda_0$ | -2000.00 | -2000.00 | -2000.00 | -2000.00 | -2000.00 | -2000.00 |
| $(M_1, M_2, M_3)$ | 3781.13, 16179 | 3670.1318, 1695 | 3880.1402, 1842 | 3696.1338, 1763 | 3722.1811, 1534 | 3912.1416, 1865 |
| $\mu$ | 1224.92 | 1224.92 | 1224.92 | 1224.92 | 1224.92 | 1224.92 |
| $\tan \beta$ | 10.00 | 10.00 | 10.00 | 30.00 | 30.00 | 30.00 |
| $(m_{\tilde{L}}, m_{\tilde{R}})$ | 2510.23, 3534.60 | 3364.87, 4134.98 | 2140.52, 3338.13 | 2156.49, 3258.35 | 3047.09, 3394.37 | 2066.61, 3308.62 |

in red dots) is way too small to be probed via the shown IceCube exclusion limits (both the existing and the projected limits). As mentioned before, here the spin-dependent cross section is obtained via indirect means of searching for muon neutrinos at IceCube arising out of dark matter annihilation within the Sun. We note that in comparison with the 75 model (Fig.4) the SD-cross section is little larger in the 200 model because of relatively smaller mass of wino (Eq.11). We will soon discuss the muon flux limit in relation to the mass of dark matter.

Figs.10(a) and 10(b) show $<\sigma v>$ as a function of $m_{\tilde{L}}$ for the 200 model with $\tan \beta =10$ and $\tan \beta =30$ respectively. Fermi-LAT constraint (LAT dwarf spheroidal stacking (4 years) ) is shown as a green line. The red points correspond to parameter points that satisfy the relic density bound. Similar to Fig.5, the parameter space for the 200 model is practically unconstrained by the present Fermi limit.

Fig.11(a) and Fig.11(b) show the results of muon flux with respect to the mass of LSP.
Figure 8: (a) Spin independent scattering cross-section of LSP with proton as a function of LSP mass for the 200 model with $\tan\beta = 10$. The constraints coming from direct detection experiments like XENON100, LUX, future XENON1T are shown. (b) Similar plot as (a) for $\tan\beta = 30$.

Figure 9: Variation of spin dependent cross section with the LSP mass for the 200 model with $\tan\beta = 10$. IceCube exclusion limit for the $\tilde{\chi}_1^0 \tilde{\chi}_1^0 \rightarrow W^+ W^- \, \text{channel}$ is shown as a green line. The blue line represents the expected sensitivity reach of IceCube. (b) Similar plot as (a) for $\tan\beta = 30$. 
**Figure 10:** (a) DM self annihilation cross-section as a function of DM mass for the 200 model with $\tan \beta = 10$. Fermi-LAT constraint [LAT dwarf spheroidal stacking (4 years)] [52] is shown as a green line. The parameter space is practically unconstrained by Fermi data. (b) Similar plot as (a) for $\tan \beta = 30$.

for $\tan \beta = 10$ and 30 respectively for the 200 model. The IceCube exclusion limit for the $\tilde{\chi}_1^0 \tilde{\chi}_1^0 \rightarrow W^+ W^-$ channel is shown as green line [49]. The blue line represents the expected sensitivity reach of IceCube. Clearly, IceCube would not be able to probe the region of parameter space that satisfies the relic density limits.
Figure 11: Variation of muon flux with the LSP mass for the 200 model with $\tan\beta = 10$. IceCube exclusion limit for the $\tilde{\chi}_{1}^{0}\tilde{\chi}_{1}^{0} \rightarrow W^+W^-$ channel is shown as a green line. The blue line represents the expected sensitivity reach of IceCube. (b) Similar plot as (a) for $\tan\beta = 30$. 
6 Conclusion

The LHC SUSY searches and discovery of a Higgs boson at 125 GeV have put strong lower bounds on superparticle masses. Consequently the CMSSM/mSUGRA, with typically bino-dominated LSP leads to an overabundance of DM relic density over most of its parameter space. There are only a few strips of parameter space giving WMAP/PLANCK compatible DM relic density, each of which requires a significant amount of fine-tuning amongst the SUSY mass parameters. Moreover, large parts of the stau coannihilation region and the resonant annihilation region are disallowed by the Higgs mass constraint, while the focus point region is strongly disfavored by the direct DM search experiments. The higgsino LSP region can account for the right DM relic density for a LSP mass of about 1 TeV, while satisfying the Higgs mass and other experimental constraints; but it implies large squark/gluino masses \( \gtrsim 8-10 \) TeV, which are inaccessible at LHC. On the other hand, nonuniversal gaugino mass models corresponding to the 75 and 200 representations of SU(5) GUT group naturally predict higgsino dominated LSP, which can account for the right DM relic density for a LSP mass of about 1 TeV as in the case of CMSSM but with much reduced fine-tuning. Moreover, it implies gluino masses in the region of 2-3 TeV in these models, at least a part of which is accessible to high luminosity LHC runs at 14 TeV. We list the SUSY spectra for a set of benchmark points in this region of the two nonuniversal guino mass models along with the corresponding gluino pair-production cross-sections at 14 TeV LHC. We also briefly discuss the distinctive signatures of these signal events. We then discuss the prospects of detecting these two model signals in various direct and indirect DM detection experiments. For both the models these signal cross-sections turn out to be quite small. The smallness of spin-independent direct detection cross-section \( \sigma_{p\chi}^{SI} \) in the above two models arises from the facts that i) LSP is mostly higgsino-like with very little bino or wino components and ii) masses of bino and wino in the two models are large for a given mass of gluino in comparison to what is found in CMSSM. \( \sigma_{p\chi}^{SI} \) is little higher in the 200 model compared to the same in the 75 model because of relatively smaller mass of wino for the former model. The results show that a significant amount of parameter space is allowed by LUX and will be probed.
by future direct detection experiments like XENON1T. We also evaluate the spin-dependent cross-section $\sigma_{pX}^{SD}$ for the two models. It is found that for the characteristic zones of $m_{\tilde{\chi}_1}^0$ that satisfy the relic density limits, the masses of bino and wino are sufficiently high so as to cause some suppression effect. $\sigma_{pX}^{SD}$ becomes quite small to be probed via IceCube. Regarding the indirect detection signals, the photon signal intensity is small because of general lack of s-channel Higgs resonance arising out of the characteristic spectra of NUGM models that involve the given mass relations among gaugino mass parameters, RGEs and REWSB. The thermally averaged annihilation cross-section lies well below the Fermi-LAT limit. Similarly the muon flux values are too low to be probed by IceCube. One finds that the two NUGM models would be probed better via measurement of spin-independent direct detection cross section via XENON1T rather than any other direct and indirect detection of dark matter experiments.

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