Non-zero trilinear parameter in the mSUGRA model - dark matter and collider signals at Tevatron and LHC

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Abstract

Regions of the parameter space in the minimal super-gravity (mSUGRA) model with small m_0 and small $m_{1/2}$ consistent with the WMAP data on dark matter relic density and the bound on the mass of the lightest Higgs scalar from LEP2 (m_h > 114.4 GeV) open up if the rather adhoc assumption A_0=0 is relaxed. For moderate to large negative values of A_0 in several processes including lightest supersymmetric particle (LSP) pair annihilation, LSP - lighter tau slepton ($\tilde{\tau}_1$) co-annihilation and LSP - lighter top squark ($\tilde{t}_1$) co-annihilation contribute to the observed dark matter relic density. Such a $\tilde{t}_1$ can be observed at the current experiments at the Tevatron. At the LHC a very distinctive semi-inclusive signature $\tau^{\pm}$+X_τ (anything without a tau lepton) with a characteristic size much larger than $e^{\pm}$+X_e or $\mu^{\pm}$+X_μ events can be observed during the early runs.

1 Introduction

The Minimal Supersymmetric standard Model (MSSM) with R parity conservation is an attractive model because it provides a stable, weakly interacting lightest neutralino $\tilde{\chi}_1^0$ assumed to be the lightest supersymmetric particle (LSP) which turns out to be a good candidate for the observed cold dark matter (CDM) in the universe.

The number of soft SUSY breaking parameters in the most general MSSM being rather large the simplest gravity mediated SUSY breaking model - the minimal supergravity (mSUGRA) model which has only five free parameters is often employed for phenomenological analyses. These are the common gaugino and scalar mass parameters $m_{1/2}$ and m_0, the common trilinear coupling parameter A_0, all given at the gauge coupling unification scale ($M_G \sim 2 \times 10^{16}$ GeV), the ratio of the two Higgs vacuum expectation values at the electroweak scale ($\tan\beta$) and the sign of μ, the higgsino mixing parameter.

SUSY models have been constrained by the data from the Wilkinson Microwave Anisotropy Probe (WMAP) [1] on cold dark matter relic density.

$$0.09 < \Omega_{CDM}h^2 < 0.13 \tag{1}$$

where $\Omega_{CDM}h^2$ is is the DM relic density in units of the critical density, $h = 0.71 \pm 0.026$ is the Hubble constant in units of 100 Km s^{-1} Mpc^{-1}.

In the mSUGRA parameter space with low m_0 and $m_{1/2}$ the annihilation of a pair of $\tilde{\chi}_1^0$ or the co-annihilation of the LSP with nearly mass degenerate sparticles may contribute significantly to the dark matter relic density. However the Higgs mass limit from LEP2 for $A_0 = 0$ (see, e.g., LEPSUSY working group figures in Ref.[3])forces $m_{1/2}$ to be rather large and LSP pair annihilation leads to relic densities much above the upper limit permitted by the WMAP constraint. Negative A_0 allows low $m_{1/2}$ values consistent with the m_h bound from LEP2 and consequently the bulk annihilation region in mSUGRA parameter space where LSP-LSP annihilation is the dominant mechanism of producing CDM relic density open up. We have studied the collider signals corresponding to this region.

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2 The DM Allowed Parameter Space for Non-zero A_0 and the Sparticle Spectrum

In this section we study the scenarios with small m_0, small $m_{1/2}$ and negative A_0 consistent with WMAP data and m_h bound on LEP2. Negative A_0 pushes up m_h above the experimental lower bound from LEP2 even for small $m_{1/2}$. This happens through the radiative corrections to m_h. However for large negative A_0, A_t - the trilinear coupling in the top squark sector at the weak scale also picks up a larger negative value. As a result the lighter top squark becomes much lighter than other squarks. As usual the lighter stau is also rather light compared to the other sleptons.

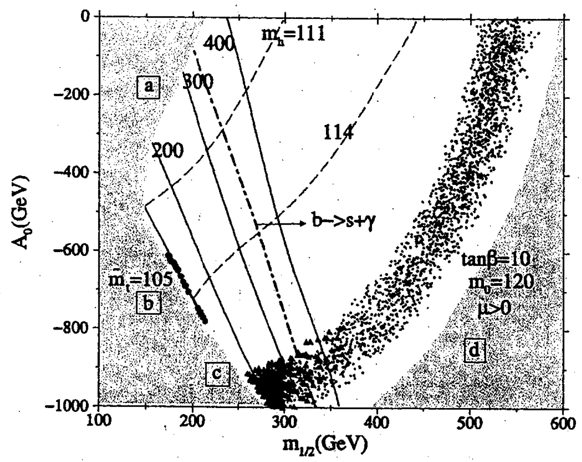

Figure 1: WMAP allowed region in the $m_{1/2} - A_0$ plane for $\tan\beta = 10$ and $m_0 = 120$. For details, see Fig 1 of Ref 2.

Fig.1 shows different WMAP allowed zones in the $(A_0 - m_{1/2})$ plane for $\tan\beta = 10$, $m_0 =$ 120 GeV. Allowing for the theoretical uncertainties in the prediction for m_h, we have identified the regions corresponding to 111 GeV $< m_h <$ 114 GeV (the uncertain zone) and $m_h >$ 114 GeV (the regular zone). In principle both the regions are allowed by the LEP data. The WMAP data allowed parameter space has three distinct regions (for details, see Ref 2).

- In the region marked by the red dots (dark dots near region (b)) the LSP-stop co-annihilation is the dominant mechanism for relic density production.
- In the region marked by the blue (deep shaded) dots neutralino pair annihilation is the main mechanism for producing the observed relic density.
- There is a third WMAP allowed region for larger $m_{1/2}$ (the pink/light shaded dots). Here $\tilde{\tau}_1$-LSP co annihilation dominates over LSP annihilation.

The favoured parameter spaces for other choices of m_0 and $\tan\beta$ can be found in Ref 2. In all cases with negative A_0 the allowed magnitude of $m_{1/2}$ may be significantly smaller than that for the $A_0 = 0$ case. This leaves open the possibility that the squark and gluinos are relatively light and may show up during the early runs of the LHC.

3 The Novel Collider Signals for non-zero values of the trilinear coupling

In this section we simulate all possible squark - gluino events using Pythia (version 6.409) at the LHC energy ($\sqrt{s}$=14 TeV). We compute the relevant BRs using the program SDECAY.

From Fig 1 we have chosen three benchmark points (seen Table 1 of Ref 2): A)(from the pink region), B)(from the lower part of the blue region) and C) (corresponding to the lowest $m_{1/2}$ in the blue region for $A_0 = 0$). The squark and gluino masses increase as we go from A) - C). We next computed the total lowest order squark-gluino production cross-sections [2] for three benchmark points. The total squark-gluino cross-section for scenario A) is much greater compared to that of B) and C).

Squark gluino events are then generated by Pythia. In the parton level analyses all SM particles other than W,Z and t are treated stable. We also impose the basic cuts $p_T > 30.0$ GeV and $|\eta_l| < 2.5$ on e, μ and τ only. The significant excess of events involving the τ slepton can be seen from Table 1. A large fraction of the events will be accompanied by b-jets.

	A	B	C
$1\tau + X_\tau$	29870	11860	1340
$1\mu + X_\mu$	5274	4251	1260
$1e + X_e$	5294	4232	1262
$1\tau + 0b + X_\tau$	10750	4581	747
$1\tau + 1b + X_\tau$	19	13	1
$1\tau + 2b + X_\tau$	17099	6589	507
$1\tau + 3b + X_\tau$	9	6	0
$1\tau + 4b + X_\tau$	425	665	80

Table 1: The number of semi-inclusive events with one τ, one e and one μ at the parton level.

We next incorporate initial and final state radiation, hadronization, fragmentation, jet formation and τ detection efficiencies and generate squark- gluino events by Pythia. We also apply generic ATLAS type cuts used for squark-gluino searches (see Ref 2). The results along with the dominant background events from $t\bar{t}$ production are in Table 2.

	A	B	C	$t\bar{t}$
$1\tau + X_\tau$	3113	1402	239	481
$1\mu + X_\mu$	1179	1246	820	1295
$1e + X_e$	1138	1263	829	1354

Table 2: The number of semi-inclusive events with one detected τ jet, one isolated e and one isolated μ computed by Pythia.

The main reason for this "non-universality" in the lepton sector lies in the dominant 2 - body decay modes of $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$ involving the lighter τ slepton. This feature can be understood from Tables 3-5 in Ref 2.

4 Conclusion

In this work we have shown that the bound on higgs mass can be satisfied for small m_0 and small $m_{1/2}$ with negative A_0 resulting in the revival of the bulk annihilation region. Upcoming hadron collider experiments can probe bulk of this parameter space where squarks and gluinos are relatively light. Excess of τ events over the corresponding e or μ events provides a spectacular signature.

Acknowledgment

SP would like to thank the Summer Institute 2007 held at Fuji Yoshida, Japan for giving him the opportunity to deliver the short talk and also for the full financial assistance. He would also like to thank the Council of Scientific and Industrial Research, Govt.of India for a research fellowship.

References

[1] D. N. Spergel *et al.*, arXiv:astro-ph/0603449.

[2] For details and further references, see Utpal Chattopadhyay, Debottam Das,Amitava Datta and Sujoy Poddar,Phys. Rev. D **76**, 055008 (2007).

[3] http://lepsusy.web.cern.ch/lepsusy/www/lspmsugra_summer02/02-06.2/mSUGRA_208.html