Stop as a next-to-lightest supersymmetric particle in CMSSM

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SUSY12
August 14th, Beijing

Phys.Rev. D84 (2011) 075021
arXiv:1207.2429 [hep-ph]

Outline

- Constrained MSSM
- Stop NLSP
- Search at LHC

In Constrained MSSM (mSUGRA scenario), the parameters of the model are the boundary conditions of common soft supersymmetry breaking terms at the unification scale m_0, $\mathrm{m}_{1/2}$ and A_0, and the ratio of vacuum expectation values $\tan\beta$, and $\mathrm{sign}(\mu)$.

Constraints

- Low energy observables
    - $B \to \tau\nu$
    - $b \to s\gamma$
    - $B_s \to \mu^+\mu^-$
    - $(g-2)_\mu$
- Mass constraints from accelerator searches
- Higgs mass
- Dark matter

Dark matter relic density and the Higgs mass limit the CMSSM parameter space considerably.

Stop can be the NSLP when the mixing term of left and right stop states in the mass matrix is large.

$$\mathbf{m}^2_{\tilde{t}} = \begin{pmatrix} m^2_{Q_3} + m^2_t + \Delta_u & m_t(A_t - \mu \cot \beta) \\ m_t(A_t - \mu \cot \beta) & m^2_{\bar{u}_3} + m^2_t + \Delta_{u_r} \end{pmatrix}$$

The largest mixing occurs when μ and A_t have the opposite signs. A large mixing causes stop mass states to split to light and heavy stops.

Additionally, renormalization group equation running is important.

Terms proportional to Yukawa couplings (and scalar masses) decrease the soft masses,
while terms proportional to gauge couplings (and gaugino masses) increase the soft masses.
Stop NLSP therefore, because of the large Yukawa and gauge coulings, favors a small $m_{1/2}$ compared to m_0.

Approximating Higgs one-loop mass in MSSM, stops are the most important contribution:

$$m_h^2 = m_Z^2 \cos 2\beta + \frac{3m_t^4}{4\pi^2 v^2} \left(\ln \frac{m_S^2}{m_t^2} + \frac{X_t^2}{M_S^2} \left(1 - \frac{X_t^2}{12 M_S^2} \right) \right),$$
$$X_t = A_t - \mu \cot \beta.$$

LHC's discovery of 125 GeV Standard Model like Higgs boson requires in the MSSM either heavy scalars or nearly maximal mixing ($X_t = \sqrt{6} M_S$).

Neutralino is a promising dark matter candidate. Dark matter relic density is too high in most of the parameter space. Co-annihilation between LSP and the next lightest supersymmetric particle can reduce the relic density substantially.

- WMAP cold dark matter density $\Omega_c h^2 = 0.1126 \pm 0.0036$
- To obtain correct relic density with co-annihilation, the mass difference should be greater than 20 GeV and less than 50 GeV between the LSP and the NLSP

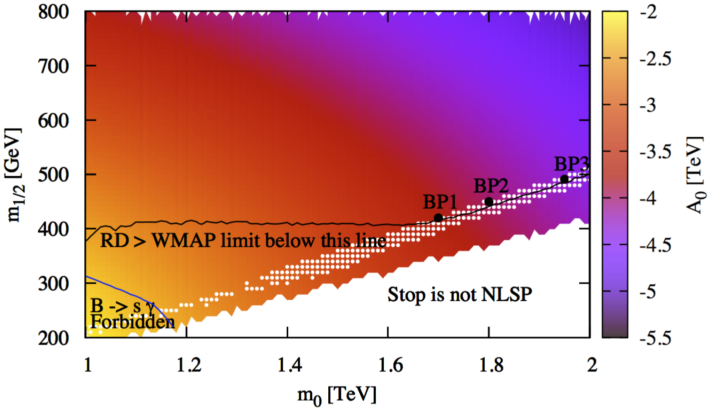

Figure : The 3-dimensional parameter space gives rise to stop NLSP, for $\tan\beta = 15$ and $\mu > 0$. To select a particular value for A_0, we demand $m_{\tilde{t}_1} - m_{\tilde{\chi}_0^1} = 35$ GeV. The white dots correspond to the points resulting in a $m_h - 125 \pm 2$ GeV.

When stop is the NLSP and $m_{\tilde{t}_1} - m_{\tilde{\chi}_0^1} < m_W$, the only possible stop decays are

- $\tilde{t}_1 \to u\tilde{\chi}_0^1$,
- $\tilde{t}_1 \to c\tilde{\chi}_0^1$,
- $\tilde{t}_1 \to bf\bar{f}'\tilde{\chi}_0^1$.

The loop decay $\tilde{t}_1 \to c\tilde{\chi}_0^1$ is the dominant decay mode. The other loop decay is suppressed by a smaller CKM matrix element.

How to search for stops in stop NLSP scenario? Stops can be produced directly (large cross section) or from gluinos (small cross section). In direct production, stops decay to charm quarks and neutralinos.

- $pp \to \tilde{t}_1 \tilde{t}_1^* \to c\bar{c}\tilde{\chi}_0^1 \tilde{\chi}_0^1 \to c-\texttt{jets} + \text{missing energy}$

Unfortunately, the signature of two c-jets and missing energy is difficult because the small mass difference of neutralino and the NLSP stop causes charm quarks to be soft.
More promising signatures come from gluino production

- $pp \to \tilde{g}\tilde{g} \to tt\tilde{t}_1^*\tilde{t}_1^*, t\bar{t}\tilde{t}_1\tilde{t}_1^*, \overline{tt}\tilde{t}_1\tilde{t}_1$

Top quarks then decay either hadronically or leptonically, giving rise to multi-jet$+$ $\not{E}_T$ or leptons $+$ $\not{E}_T$ signature, which are challenging to separate from the large Standard Model $t\bar{t}$ background. One possibility is to use two b-jets and same-sign leptons $+$ $\not{E}_T$ for signature.

TABLE I. Benchmark parameters in GeV ($\tan\beta = 15$, $\mu > 0$).

BP1			BP2			BP3		
m_0	$m_{1/2}$	A_0	m_0	$m_{1/2}$	A_0	m_0	$m_{1/2}$	A_0
1700	420	-3763	1800	450	-4001	1950	491	-4349

TABLE II. Masses (in GeV) of relevant sparticles.

	$\tilde{g}$	$\tilde{u}_L$	$\tilde{u}_R$	$\tilde{t}_2$	$\tilde{t}_1$	$\tilde{b}_2$	$\tilde{b}_1$	$\tilde{\chi}_1^{\pm}$	$\tilde{\chi}_1^0$
BP1	1064	1880	1872	1334	217	1776	1287	352	181
BP2	1133	1994	1985	1411	229	1883	1365	378	194
BP3	1227	2161	2150	1523	250	2040	1478	414	213

TABLE III. Model contribution to different observables.

BPs	m_h	$\Omega_c h^2$	$\mathrm{BR}(B \to X_s\gamma)$	$\mathrm{BR}(B_s \to \mu^+\mu^-)$	$R^{NP}_{\tau\nu_\tau}$
BP1	124.0	0.115	2.77×10^{-4}	3.14×10^{-9}	0.997
BP2	124.1	0.108	2.82×10^{-4}	3.13×10^{-9}	0.998
BP3	125.3	0.131	2.89×10^{-4}	3.12×10^{-9}	0.998

TABLE IV. Signal and SM background cross-sections at the LHC with $\sqrt{s} = 14$ TeV after different set of cuts.

Process	SM Background cross-section in fb			
	Acc. Cuts	Acc. Cuts + $\not{E}_T \geq$ 100 GeV	Acc. Cuts + $\not{E}_T \geq$ 300 GeV	Acc. Cuts + $\not{E}_T \geq$ 500 GeV
$t\bar{t}$	60.09	1.29	8.1×10^{-2}	$<1.5\times10^{-3}$
jets	51.32	0.26	6.2×10^{-3}	$<3.1\times10^{-3}$
$t\bar{t}Z$	0.0022	1.6×10^{-3}	3.2×10^{-4}	$<3.4\times10^{-4}$
$t\bar{t}W$	0.074	2.7×10^{-2}	2.8×10^{-3}	9.2×10^{-4}
BPs	Signal cross-section in fb			
BP1	2.49	2.32	1.51	0.76
BP2	1.75	1.66	1.19	0.73
BP3	1.22	1.16	0.87	0.57

We propose to use boosted tops to reduce the SM background. Since $m_{\tilde{g}} \gg m_{\tilde{t}_1}$, stop and top from the gluino decay will be boosted.

Top jets can be tagged.

With high p_T cuts for the top jets and large missing $\not{E}_T$ from the neutralino requirement the background can be highly reduced.

Conclusion

- Mass of Higgs boson supports the stop NLSP scenario in CMSSM
- Co-annihilation can provide with correct dark matter density
- Interesting signature from boosted tops!