Strong Sector in non-minimal SUSY model

QCD@Work 2016

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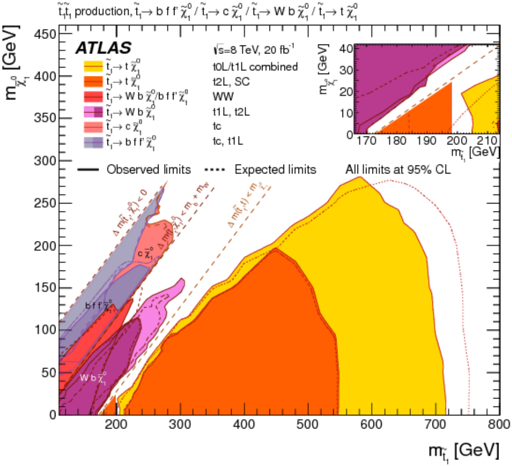
27 June 2016

Mass correlation plot of $\tilde{t}_1$ vs. $\tilde{\chi}_1^0$
Third-generation squark search from ATLAS
Eur.Phys.J. C75 (2015) no.10, 510



Contents

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and

$$\mathcal{W}_{Higgs} = \mu \, \hat{H}_u \cdot \hat{H}_d . \tag{3}$$

Higgs superfields are given by

$$\hat{H}_u = \begin{pmatrix} \hat{H}_u^+ \\ \hat{H}_u^0 \end{pmatrix}, \qquad \hat{H}_d = \begin{pmatrix} \hat{H}_d^0 \\ \hat{H}_d^- \end{pmatrix}. \tag{4}$$

Stop and sbottom mass matrices are given respectively by

$$m_{\tilde{t}} = \begin{pmatrix} m_t^2 + m_{Q_3}^2 + m_Z^2 \cos(2\beta)(\frac{1}{2} - \frac{2}{3}\sin^2\theta_w) & m_t(A_t - \mu\cot\beta) \\ m_t(A_t - \mu\cot\beta) & m_t^2 + m_{\bar{u}_3}^2 - \frac{1}{3} mZ^2 \cos(2\beta)\sin^2\theta_w \end{pmatrix} \quad (5)$$

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The mixing $\tilde{t}_R - \tilde{t}_L$ is relevant and $\tilde{t}_1$ is the lightest squark

$$\begin{aligned} m^2_{\tilde{t}_{1,2}} &= \frac{1}{2}\Big(m_t^2 + m_{Q_3}^2 + 2m_t^2 + \frac{1}{2} m_Z^2 \cos(2\beta) \\ &\pm \sqrt{(m_{Q_3}^2 - m_{\tilde{u}_3}^2 + (\frac{1}{2} - \frac{4}{3}\sin^2\theta_w)\cos(2\beta) m_Z^2)^2 + 4m_t^2(A_t - \mu\cot\beta)^2}\Big) \end{aligned}$$

Contents

Triplet & Singlet

The superpotential of the model[1] is $\mathcal{W}_{TNMSSM} = \mathcal{W}_{MSSM} + \mathcal{W}_{TS}$ with

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and

$$\mathcal{W}_{TS} = \lambda_T \hat{H}_d \cdot \hat{T} \hat{H}_u + \lambda_S \hat{S} \hat{H}_d \cdot \hat{H}_u + \frac{\kappa}{3} \hat{S}^3 + \lambda_{TS} \hat{S} \mathrm{tr}[\hat{T}^2]. \tag{8}$$

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Triplet and doublets superfields are given by

$$\hat{T} = \begin{pmatrix} \sqrt{\frac{1}{2}} \hat{T}^0 & \hat{T}_2^+ \\ \hat{T}_1^- & -\sqrt{\frac{1}{2}} \hat{T}^0 \end{pmatrix}, \qquad \hat{H}_u = \begin{pmatrix} \hat{H}_u^+ \\ \hat{H}_u^0 \end{pmatrix}, \qquad \hat{H}_d = \begin{pmatrix} \hat{H}_d^0 \\ \hat{H}_d^- \end{pmatrix}. \tag{9}$$

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In any scale invariant supersymmetric theory with a cubic superpotential, the complete Lagrangian with the soft SUSY breaking terms has an accidental Z_3 symmetry. Such terms are given by

$$\begin{aligned} V_{soft} \;=\;& m^2_{H_u}|H_u|^2 + m^2_{H_d}|H_d|^2 + m^2_S|S|^2 + m^2_T|T|^2 \\ & + m^2_Q|Q|^2 + m^2_U|U|^2 + m^2_D|D|^2 \\ & +(A_S S H_d\cdot H_u + A_\kappa S^3 + A_T H_d\cdot T\cdot H_u \\ & + A_{TS} S Tr(T^2) + A_U U H_U\cdot Q + A_D D H_D\cdot Q \\ & + h.c.), \end{aligned} \tag{10}$$

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We have performed the scan using the following criteria for the couplings and the soft parameters

$$\begin{gathered} |\lambda_{T,S,TS}| \leq 1,\ |\kappa| \leq 3,\ |v_s| \leq 1\,\mathrm{TeV},\ 1 \leq \tan\beta \leq 10, \\ |A_{T,S,TS,U,D}| \leq 1\,\mathrm{GeV},\ |\mathrm{A}_\kappa| \leq 3\,\mathrm{GeV}, \\ 65 \leq |M_{1,2}| \leq 10^3\,\mathrm{GeV},\ 3\times10^2 \leq \mathrm{m_{Q_3,\bar{u}_3,\bar{d}_3}} \leq 10^3\,\mathrm{GeV} \end{gathered} \tag{11}$$

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Contents

The mass matrices for stop and sbottom in this model are

$$m_{\tilde{t}} = \begin{pmatrix} m_t^2 + m_{Q_3}^2 + \frac{1}{24}\left(g_Y^2 - 3g_L^2\right)\left(v_u^2 - v_d^2\right) & \frac{1}{\sqrt{2}} A_T v_u + \frac{y_t v_d}{2}\left(\frac{v_T \lambda_T}{\sqrt{2}} - v_S \lambda_S\right) \\ \frac{1}{\sqrt{2}} A_T v_u + \frac{y_t v_d}{2}\left(\frac{v_T \lambda_T}{\sqrt{2}} - v_S \lambda_S\right) & m_t^2 + m_{\bar{u}_3}^2 + \frac{1}{6}\left(v_d^2 - v_u^2\right) g_Y^2 \end{pmatrix} \quad (12)$$

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In this model A_t is indipendent from y_t and the μ parameter of MSSM is dynamically generated through

$$\lambda_T \hat{H}_d \cdot \hat{T}\hat{H}_u + \lambda_S \hat{S}\hat{H}_d \cdot \hat{H}_u$$

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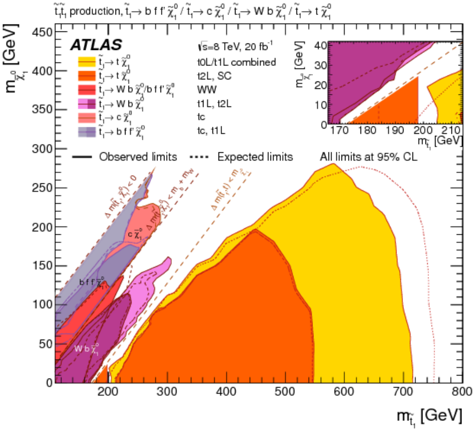
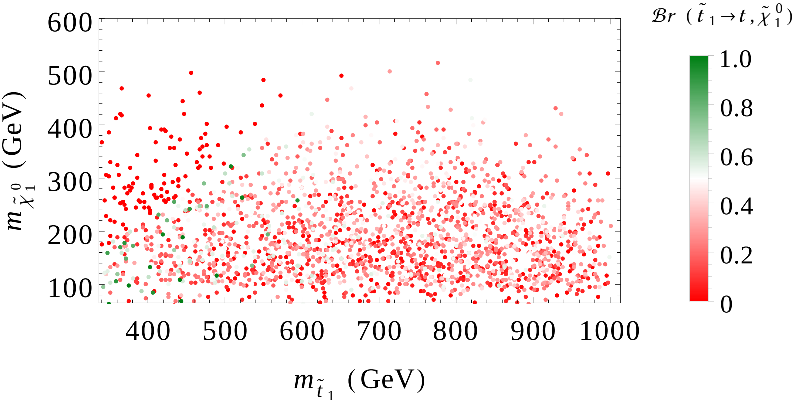
Squark searches are made usually under the assumption of

$$\mathcal{B}r(\tilde{t}_1 \to t\,\tilde{\chi}_1^0) = 1$$



However this is not always true in non-minimal SUSY theories, such as TNMSSM



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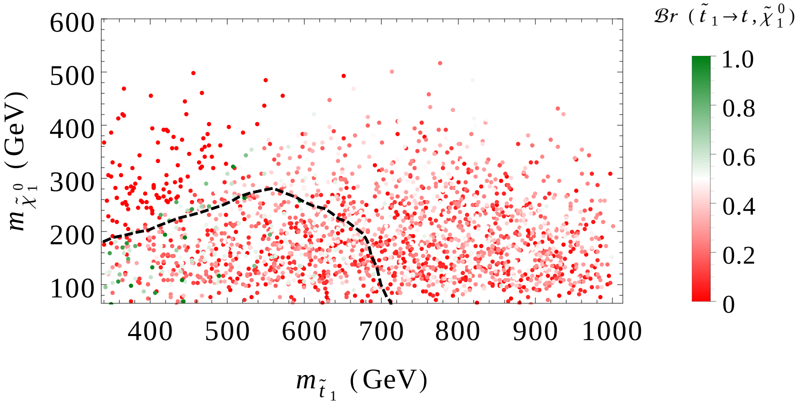

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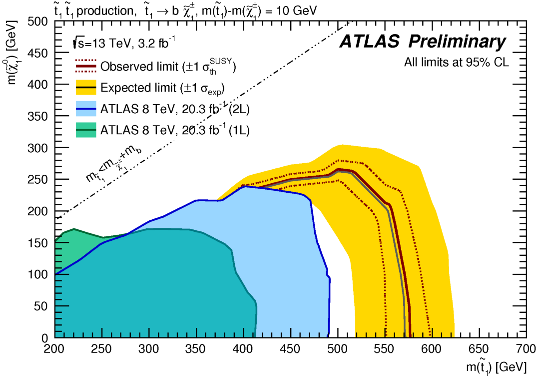
Another possibility for the squark decay is the channel

$$\tilde{t}_1 \to b\,\tilde{\chi}_1^\pm$$



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Again the channel

$$\tilde{t}_1 \to b\,\tilde{\chi}_1^{\pm}$$

is assumed to have $\mathscr{B}r = 1$ and $m_{\tilde{t}_1}$ - $m_{\tilde{\chi}_1^{\pm}} = 10$ GeV

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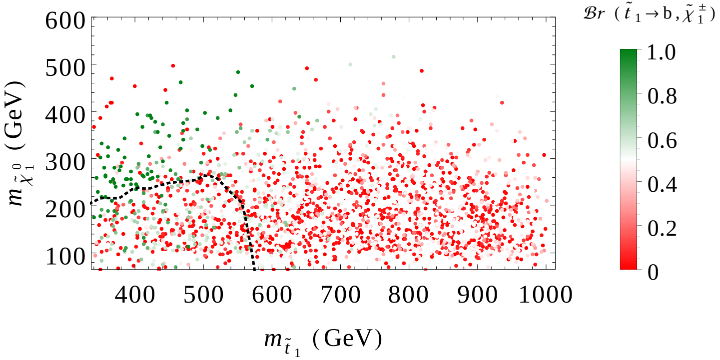

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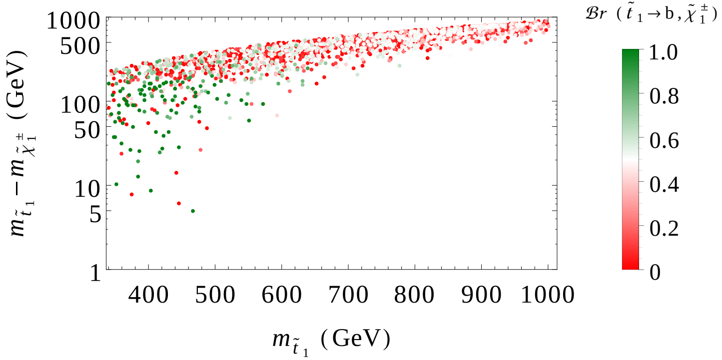
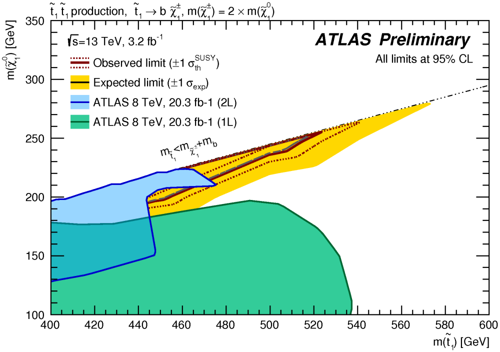


It was also analyzed the case

$$\tilde{t}_1 \to b\,\tilde{\chi}_1^{\pm}$$

with $\mathcal{Br} = 1$ and $m_{\tilde{\chi}_1^{\pm}} = 2\,m_{\tilde{\chi}_1^0}$



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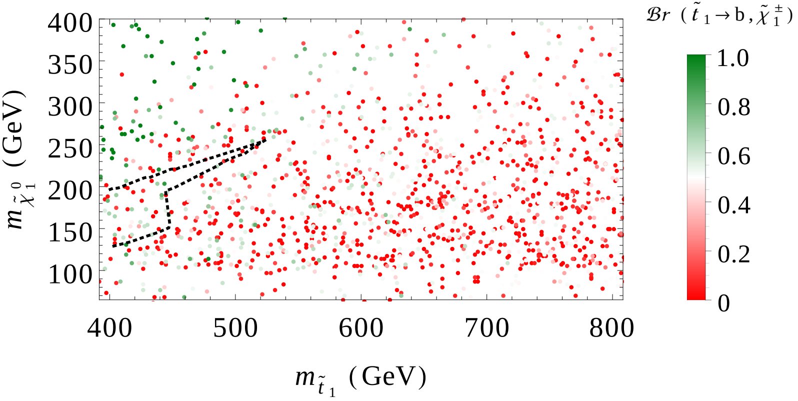

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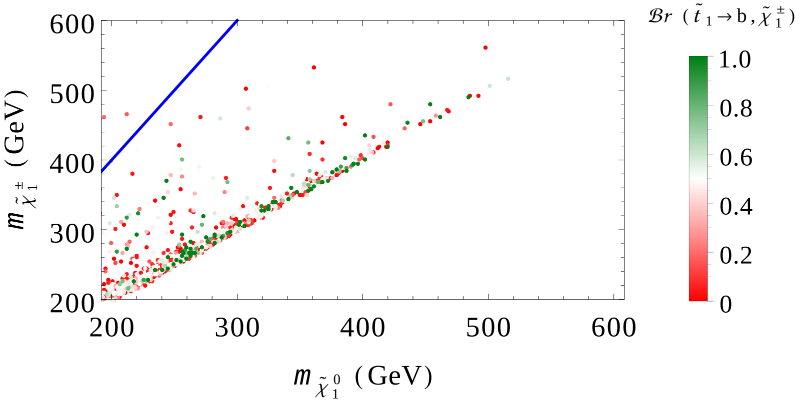

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- LHC is improoving the previous searches for superpartners of the SM quarks
- most of the attention is devoted to MSSM-like scenarios
- extensions of MSSM can have different behavior in both strong and weak sectors

Thank You!

Contents

Vacuum and Scalar Spectrum

To determine the tree-level mass spectrum, we consider the tree-level minimisation conditions,

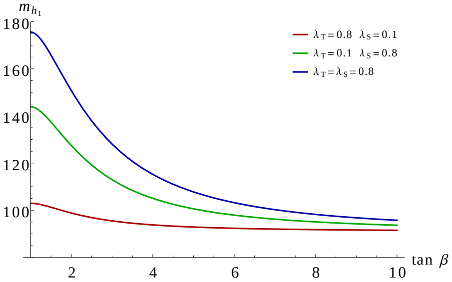
$$\partial_{\Phi_i} V|_{vev} = 0; \quad V = V_F + V_D + V_{soft}, \quad \Phi_i = H^0_{u,d}, S, T^0. \quad (14)$$

Each field takes a vacuum expectation value (v.e.v.), which we choose to be real in order to preserve CP. V_F and V_D are the supersymmetric F-terms and D-terms extracted from the superpotential. V_{soft} is the scale invariant, soft-breaking part of the potential. The minimization conditions are solved w.r.t. the soft-breaking masses of the scalars. We then have

CP-even	CP-odd	Charged
h_1, h_2, h_3, h_4	a_1, a_2, a_3	$h^\pm_1, h^\pm_2, h^\pm_3$

At tree-level the maximum value of the lightest neutral Higgs is

$$m_{h_1}^2 \leq m_Z^2\left(\cos^2 2\beta + \frac{\lambda_T^2}{g_L^2 + g_Y^2}\sin^2 2\beta + \frac{2\lambda_S^2}{g_L^2 + g_Y^2}\sin^2 2\beta\right) \quad (15)$$



Tree-level lightest CP-even Higgs mass maximum values with respect to $\tan\beta$ for (i) $\lambda_T = 0.8$, $\lambda_S = 0.1$ (in red), (ii) $\lambda_T = 0.1$, $\lambda_S = 0.8$ (in green) and (iii) $\lambda_T = 0.8$, $\lambda_S = 0.8$ (in blue).

One-Loop Higgs Masses

We calculate the one-loop Higgs mass for the neutral Higgs bosons via the Coleman-Weinberg effective potential

$$V_{\mathrm{CW}} = \frac{1}{64\pi^2}\mathrm{Str}\left[\mathcal{M}^4\left(\ln\frac{\mathcal{M}^2}{\mu_r^2} - \frac{3}{2}\right)\right], \tag{16}$$

where $\mathcal{M}^2$ are the field-dependent mass matrices, μ_r is the renormalization scale, and the supertrace includes a factor of $(-1)^{2J}(2J+1)$ for each particle of spin J in the loop.

Using the $V_{\rm CW}$ one-loop potential we have the following one-loop expression for the scalar Higgs boson mass matrix

$$\begin{aligned}
(\Delta m_h^2)_{ij} &= \left.\frac{\partial^2 V_{\rm CW}(\Phi)}{\partial\Phi_i\partial\Phi_j}\right|_{\rm vev} - \frac{\delta_{ij}}{\langle\Phi_i\rangle}\left.\frac{\partial V_{\rm CW}(\Phi)}{\partial\Phi_i}\right|_{\rm vev} \\
&= \sum_k \frac{1}{32\pi^2}\frac{\partial m_k^2}{\partial\Phi_i}\frac{\partial m_k^2}{\partial\Phi_j}\ln\left.\frac{m_k^2}{\mu_r^2}\right|_{\rm vev} \\
&\quad + \sum_k \frac{1}{32\pi^2} m_k^2 \frac{\partial^2 m_k^2}{\partial\Phi_i\partial\Phi_j}\left.\left(\ln\frac{m_k^2}{\mu_r^2}-1\right)\right|_{\rm vev} \\
&\quad - \sum_k \frac{1}{32\pi^2} m_k^2 \frac{\delta_{ij}}{\langle\Phi_i\rangle}\frac{\partial m_k^2}{\partial\Phi_i}\left.\left(\ln\frac{m_k^2}{\mu_r^2}-1\right)\right|_{\rm vev} \qquad (17)
\end{aligned}$$

where we have included the one-loop correction to the minimization conditions.