Phenomenology of the constrained Exceptional Supersymmetric Standard Model (cE_6SSM)

Alexander Voigt

Technische Universität Dresden
Institut für Kern- und Teilchenphysik

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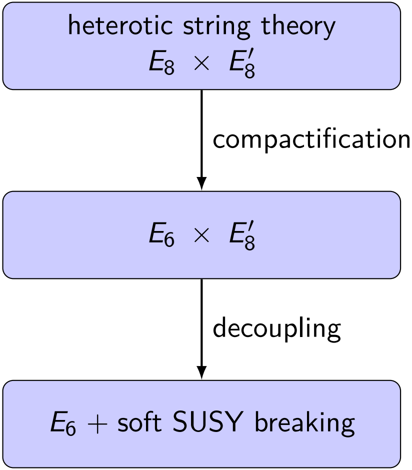
Content

Motivation by string theory



[F. del Aguila, G. A. Blair, M. Daniel, G. G. Ross, Nucl.Phys.B272 (1986)]

Motivation by the μ problem

MSSM superpotential:

$$\mathcal{W}_{\text{MSSM}} = \mu H_1 H_2 - y^u_{ij}(Q_i H_2)\bar{U}_j - y^d_{ij}(H_1 Q_i)\bar{D}_j - y^e_{ij}(H_1 L_i)\bar{E}_j$$

- bilinear term $\mu H_1 H_2$ present before SUSY breaking
- model definition at unification scale $M_X \Rightarrow \mu \sim M_X$
- but EWSB conditions imply

$$\frac{1}{2} m_Z^2 = \frac{m_{H_1}^2 - m_{H_2}^2 \tan^2\beta}{\tan^2\beta - 1} - \mu^2$$

$\Rightarrow \mu \sim m_Z$ to have $v = 174\,\text{GeV}$

[D. J. H. Chung et Al. Phys.Rept.407 (2005)]

Definition of the E_6SSM – gauge structure

[S. F. King, S. Moretti, R. Nevzorov, Phys.Rev.D73:035009 (2006)]

Definition of the E_6SSM

Supersymmetric gauge theory based on E_6 gauge group broken at GUT scale

$$E_6 \xrightarrow{\text{at GUT scale}} SU(3)_c \times SU(2)_L \times U(1)_Y \times U(1)_N$$
$$\xrightarrow{\text{above EW scale}} SU(3)_c \times SU(2)_L \times U(1)_Y$$

Definition of the E_6SSM – matter content

Matter content

- 3 complete fundamental 27 multiplets $(\mathbf{27})_i$ of E_6 $(i = 1, 2, 3)$
- 2 higgs-like doublets H', $\overline{H'}$ from $(\mathbf{27})'$, $(\overline{\mathbf{27}})'$
- Vector superfields in adjoint representation of $SU(3)_\mathrm{c} \times SU(2)_\mathrm{L} \times U(1)_Y \times U(1)_N$

Q_i, $\bar{U}_i$, $\bar{D}_i$, L_i, $\bar{E}_i$, $\bar{N}_i$	MSSM fields
S_i	$SU(3)_\mathrm{c} \times SU(2)_\mathrm{L} \times U(1)_Y$ singlet
H_{1i}, H_{2i}	higgs-like doublets
X_i, $\overline{X}_i$	exotic colored (Diquarks/ Leptoquarks)
H', $\overline{H'}$	extra higgs-like doublets
V^Y, $\vec{V}^W$, V_g^a, V^N	gauge bosons, gauginos

E_6SSM superpotential

Approximations of the general E_6SSM superpotential:

- $Z_2^{B/L}$ symmetry (analogous to R parity) and (approximate) Z_2^H symmetry to avoid proton decay and FCNC
- integrate out $\bar{N}_i$
- keep only dominant terms

$\Rightarrow$

$$\mathcal{W}_{E_6SSM} \approx -y^e_{33}(H_{13}L_3)\bar{E}_3 - y^d_{33}(H_{13}Q_3)\bar{D}_3 - y^u_{33}(Q_3H_{23})\bar{U}_3 + \lambda_i S_3(H_{1i}H_{2i}) + \kappa_i S_3(X_i\overline{X}_i) + \mu'(H'\overline{H'})$$

Note: $\mu H_{1i}H_{2i}$ forbidden by $U(1)_N$ gauge symmetry $\Rightarrow$ μ problem solved dynamically

$$\int \mathrm{d}^2\theta\, \lambda_3 S_3(H_{13}H_{23}) \quad \to \quad -\frac{\lambda_3 v_s}{\sqrt{2}}(\tilde{h}_{13}\tilde{h}_{23}) + \cdots$$

But: μ' problem introduced (but $\mu' \sim 10^{10}$ GeV possible)

Constrained E_6SSM (cE_6SSM)

[P. Athron, S. F. King, D. J. Miller, S. Moretti, R. Nevzorov, Phys.Rev.D80:035009 (2009)]

Constrained model defined by mass universality at M_X:

$$\begin{aligned} m_i(M_X) &= m_0, \\ M_i(M_X) &= M_{1/2}, \\ A_i(M_X) &= A \end{aligned}$$

Input parameters for cE_6SSM:

$$\begin{aligned} & \lambda_i(M_X), \kappa_i(M_X), m_0, M_{1/2}, A \\ \Leftrightarrow \quad & \lambda_i(M_X), \kappa_i(M_X), v, \tan\beta, v_s \end{aligned}$$

Phenomenology of the cE_6SSM

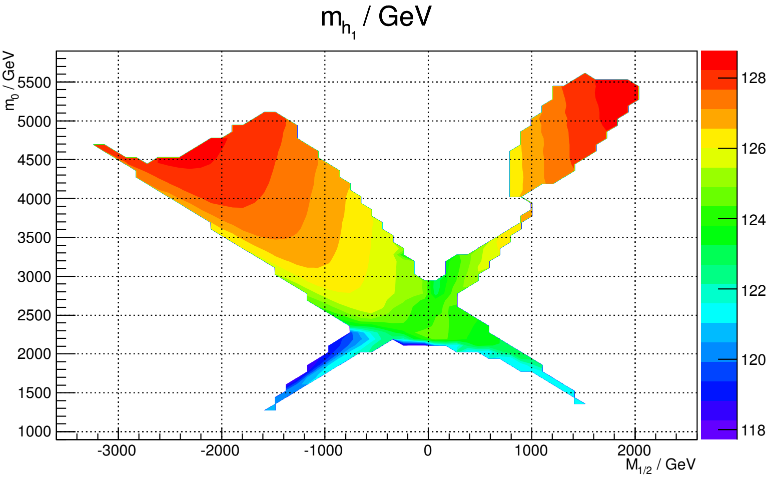


Figure: lightest CP even Higgs mass, where $\tan\beta \in [3, 50]$, $\lambda_i = \kappa_i \in [0, 3]$, $v_s = 10\,\text{TeV}$, $\mu' = m_{h'} = m_{\bar{h}'} = 10\,\text{TeV}$

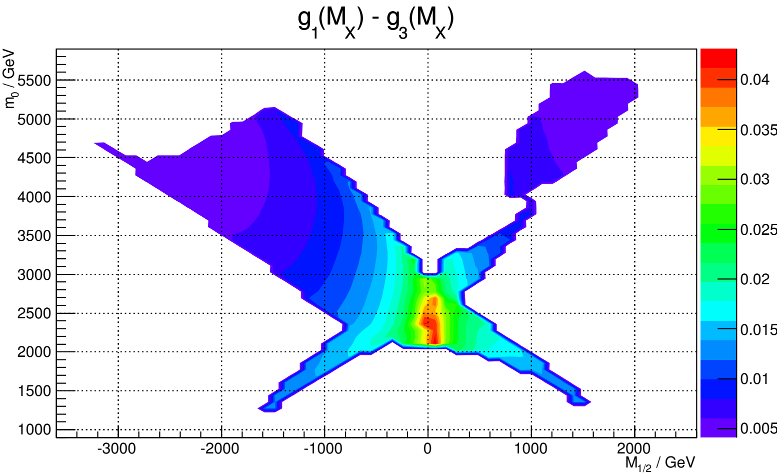


Figure: gauge coupling unification $(g_1(M_X) - g_3(M_X))$, where $\tan\beta \in [3, 50]$, $\lambda_i = \kappa_i \in [0, 3]$, $v_s = 10\,\text{TeV}$, $\mu' = m_{h'} = m_{\bar{h}'} = 10\,\text{TeV}$

Model characteristics

- light gluino $m_{\tilde{g}} \sim 0.3 \ldots 1\,\text{TeV}$ (because of large particle content $\beta_3^{1\text{L}} = 0 \Rightarrow M_3(1\,\text{TeV}) \sim 0.7 M_{1/2}$)
- sleptons considerably heavier than light gauginos (because $m_0 > |M_{1/2}|$)
- easy to have lightest Higgs mass $m_{h_1} \approx 125\,\text{GeV}$
- $\tan\beta \in [3, 50]$
    - $\tan\beta < 3$ in contrast to EWSB conditions
    - $\tan\beta > 50$ yields tachyonic masses (because additional D_N term drives $B\mu_{\text{eff}} < 0$ rapidly with $\tan\beta$)
- hard to explain $(g-2)_\mu$ (because $\tan\beta$ too small and $m_{\tilde{\mu}_i}$ too heavy)

Phenomenology of the cE$_6$SSM — LHC exclusion limits

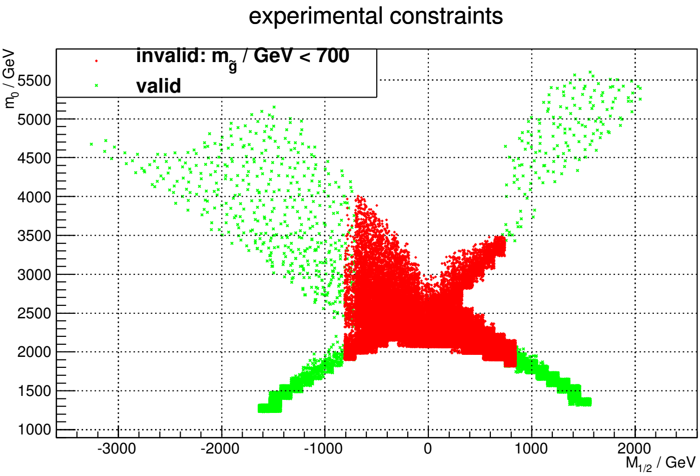


Figure: parameter space exclusion, where $\tan\beta \in [3, 50]$, $\lambda_i = \kappa_i \in [0, 3]$, $v_s = 10$ TeV, $\mu' = m_{h'} = m_{\bar{h}'} = 10$ TeV

Conclusions:

- $\sim$ half of the cE_6SSM parameter space already excluded by current LHC data
- remaining parameter space attractive for Higgs physics $m_{h_1} = 125 \ldots 130\,\text{GeV}$ and gauge coupling unification
- model not able to explain $(g-2)_\mu$

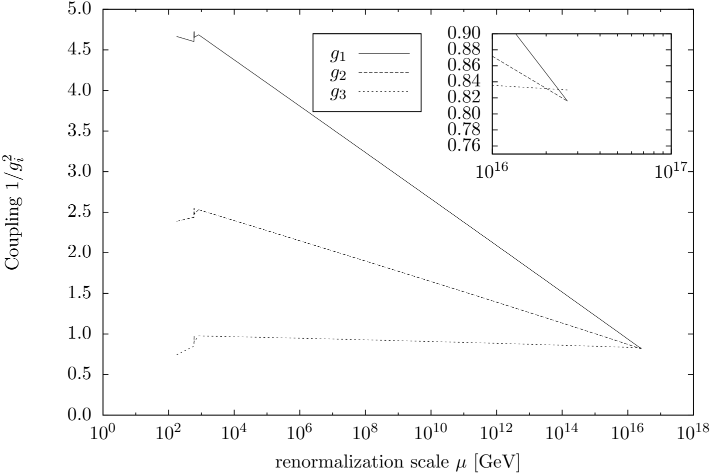


Figure: running couplings, where $\tan\beta = 35$, $\lambda_i = \kappa_i = 0.2$, $v_s = 10\,\text{TeV}$, $\mu' = m_{h'} = m_{\bar{h}'} = 10\,\text{TeV}$, solution 1

Backup

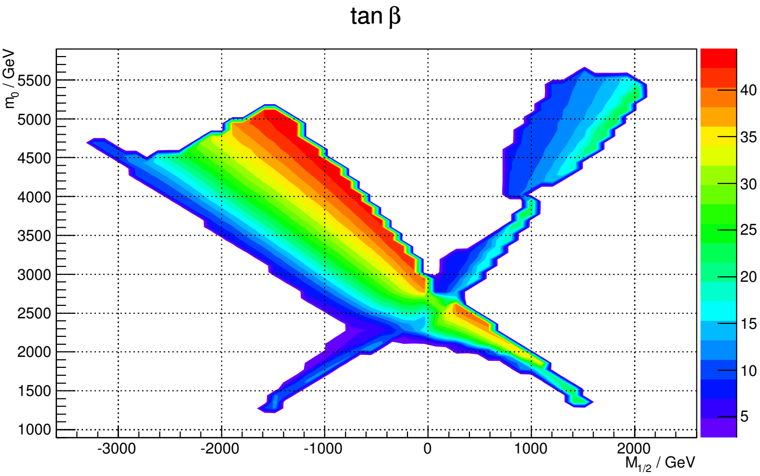


Figure: $\tan\beta(M_{1/2}, m_0)$, where $\tan\beta \in [3, 50]$, $\lambda_i = \kappa_i \in [0, 3]$, $v_s = 10$ TeV, $\mu' = m_{h'} = m_{\bar{h}'} = 10$ TeV

Backup

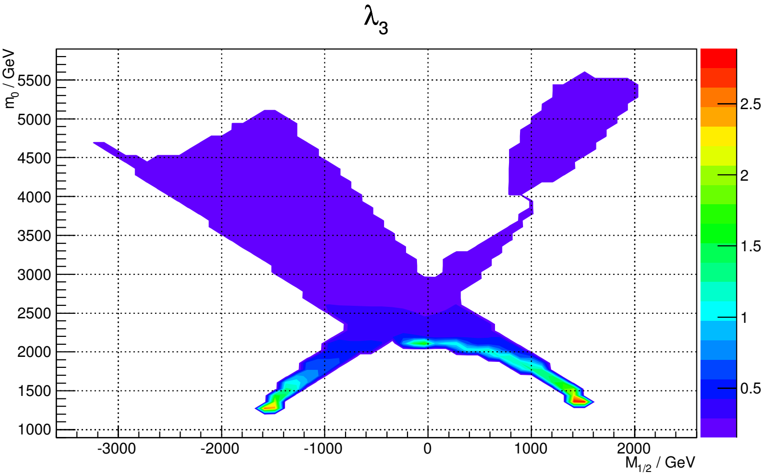


Figure: $\lambda_3(M_{1/2}, m_0)$, where $\tan\beta \in [3, 50]$, $\lambda_i = \kappa_i \in [0, 3]$, $v_s = 10\,\text{TeV}$, $\mu' = m_{h'} = m_{\bar{h}'} = 10\,\text{TeV}$