Improved precision in the constrained Exceptional Supersymmetric Standard Model (cE_6SSM)

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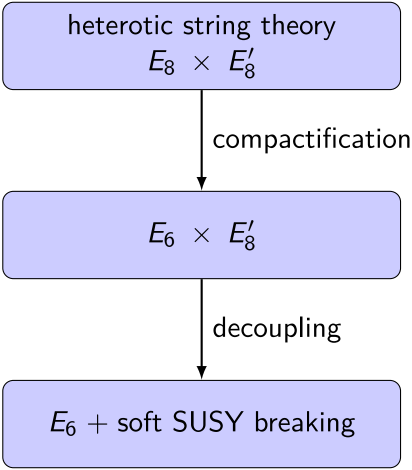
Content

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:

$$\mathcal{W}_{\text{MSSM}} = \mu H_d H_u - h^u_{ij}(H_u Q_i)u^c_j - h^d_{ij}(H_d Q_i)d^c_j - h^e_{ij}(H_d L_i)e^c_j$$

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

$$\frac{1}{2}m_Z^2 = \frac{m^2_{H_d} - m^2_{H_u}\tan^2\beta}{\tan^2\beta - 1} - \mu^2$$

$\Rightarrow \mu \sim m_Z$ 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

$$E_6 \to SU(3)_{\mathrm{c}} \times SU(2)_{\mathrm{L}} \times U(1)_Y \times U(1)_N$$

$U(1)_N$ broken above electroweak scale

$$SU(3)_{\mathrm{c}} \times SU(2)_{\mathrm{L}} \times U(1)_Y \times U(1)_N \longrightarrow SU(3)_{\mathrm{c}} \times SU(2)_{\mathrm{L}} \times U(1)_Y$$

Note: μ problem solved, because $\mu H_{1i} H_{2i}$ forbidden by $U(1)_N$

Definition of the E_6SSM – matter content

Matter content

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

Q_i, u_i^c, d_i^c, L_i, e_i^c, n_i^c	MSSM fields
S_i	$SU(3)_\text{c} \times SU(2)_\text{L} \times U(1)_Y$ 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 n_i^c, H', $\overline{H'}$
- keep only dominant terms

$\Rightarrow$

$$\mathcal{W}_{\mathrm{E_6SSM}} \approx h_t(H_u Q)t^c + h_b(H_d Q)b^c + h_\tau(H_d L)\tau^c + \lambda_i S_3(H_{1i} H_{2i}) + \kappa_i S_3(X_i \overline{X}_i)$$

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

$$\lambda_3 S_3(H_{13} H_{23}) \quad \to \quad -\frac{\lambda_3 \langle S_3 \rangle}{\sqrt{2}}(\tilde{h}_{13}\tilde{h}_{23}) + \cdots$$

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:

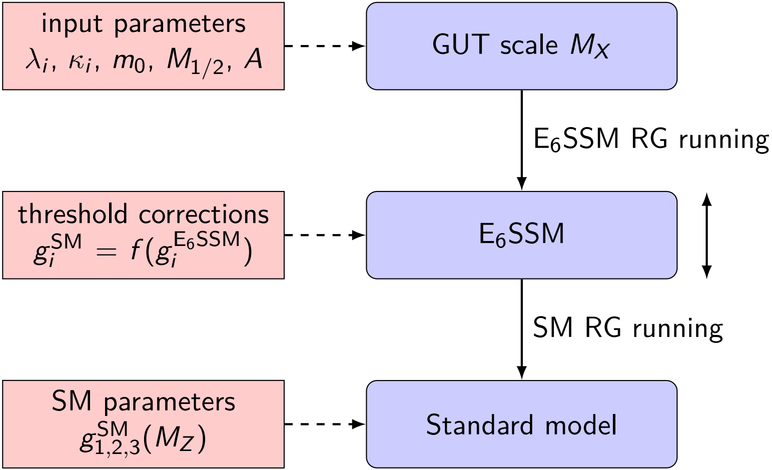
$$\begin{aligned} \text{scalar masses} &= m_0, \\ \text{gaugino masses} &= M_{1/2}, \\ \text{trilinear coupling} &= A \end{aligned}$$

Input parameters for cE_6SSM:

$$\begin{aligned} & \lambda_i(M_X), \kappa_i(M_X), m_0, M_{1/2}, A \\ \Leftrightarrow \quad & \lambda_i(M_X), \kappa_i(M_X), v, \tan\beta, \langle S_3 \rangle \end{aligned}$$

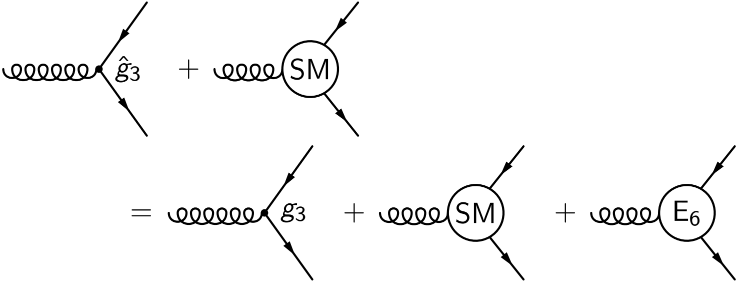
Goal: more precise prediction of particle masses in cE_6SSM

What are threshold corrections?



Threshold correction for the strong coupling

For example: g_3 (most imortant, since $\beta_3^{\text{1Loop}} = 0$)

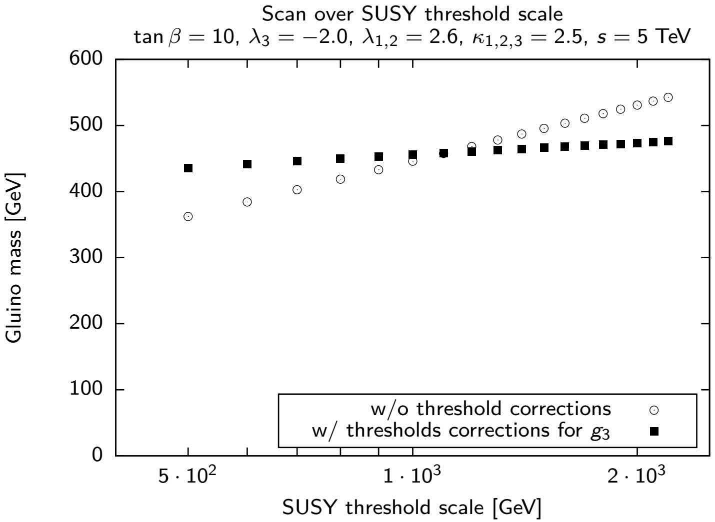


$\Rightarrow$

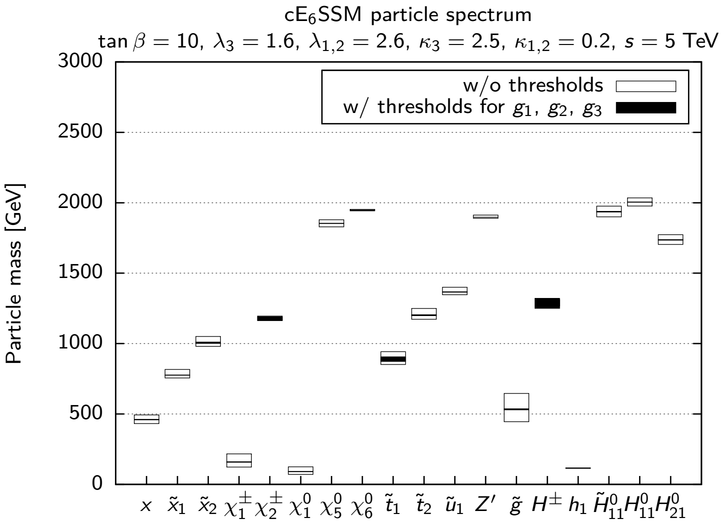
$$g_3^{\overline{\text{DR}}} = \hat{g}_3^{\overline{\text{MS}}} + \frac{\hat{g}_3^3}{(4\pi)^2}\left\{\frac{1}{2} - 2\log\left(\frac{m_{\tilde{g}}}{\mu}\right) - \frac{1}{6}\sum_{\tilde{q}}\log\left(\frac{m_{\tilde{q}}}{\mu}\right)\right.$$
$$\left. - \frac{2}{3}\sum_{x}\log\left(\frac{m_x}{\mu}\right) - \frac{1}{6}\sum_{\tilde{x}}\log\left(\frac{m_{\tilde{x}}}{\mu}\right)\right\}$$

[J. L. Hall, Nucl.Phys.B178 (1981)]

Matching scale dependency



Matching scale dependency



Conclusion and outlook

Conclusions:

- (c)E_6SSM is an interesting, well motivated model
- first study of threshold effects in cE_6SSM
- wide spectrum $\rightarrow$ threshold corrections important
- threshold corrections reduce dependency of the particle masses from the matching scale

Outlook:

Increase precision in prediction of the particle spectrum further:

- implement E_6SSM yukawa coupling threshold corrections
- 2 loop RGEs for scalar masses
- Calculate shifts to pole masses

Yukawa couplings

$$
\begin{aligned}
h_u^{\overline{\mathrm{DR}},\mathrm{E_6SSM}} &= h_u^{\mathrm{tree}} \left(1 + \frac{\delta g_2}{g_2} - \frac{\delta M_W}{M_W} + \frac{\delta m_u}{m_u} - \frac{\delta s_\beta}{s_\beta}\right)_{\mathrm{finite}} \\
h_d^{\overline{\mathrm{DR}},\mathrm{E_6SSM}} &= h_d^{\mathrm{tree}} \left(1 + \frac{\delta g_2}{g_2} - \frac{\delta M_W}{M_W} + \frac{\delta m_d}{m_d} - \frac{\delta c_\beta}{c_\beta}\right)_{\mathrm{finite}} \\
h_u^{\mathrm{tree}} &= \frac{g_2 m_f}{\sqrt{2} M_W s_\beta} \\
h_d^{\mathrm{tree}} &= \frac{g_2 m_f}{\sqrt{2} M_W c_\beta} \\
\delta M_W &= \widetilde{\mathrm{Re}}\, Z_{WW,\mathrm{T}}(M_W^2) \\
\delta m_f &= \frac{1}{2} \widetilde{\mathrm{Re}} \left[m_f \left(Z^{\mathrm{L}}_{f\bar{f}}(m_f^2) + Z^{\mathrm{R}}_{f\bar{f}}(m_f^2) \right) + Z^{\mathrm{l}}_{f\bar{f}}(m_f^2) + Z^{\mathrm{r}}_{f\bar{f}}(m_f^2) \right]
\end{aligned}
$$