

The calculation of threshold corrections in the constrained Exceptional Supersymmetric Standard Model (eE_6SSM)

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supervised by
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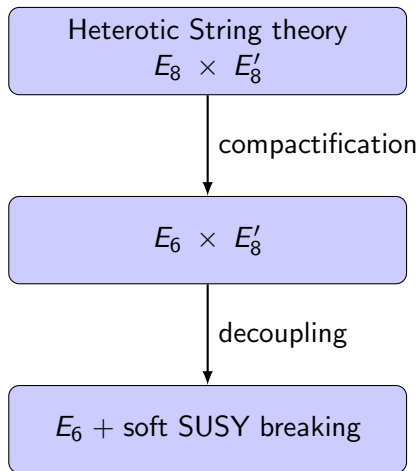
Technische Universität Dresden

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- ① The constrained Exceptional Supersymmetric Standard Model (cE₆SSM)
 - Model motivation
 - Model definition
- ② What are threshold corrections and why do we need them?
- ③ Procedure to calculate threshold corrections
 - Matching conditions
 - Threshold relation for strong coupling g_3
- ④ Results
- ⑤ Conclusions and Future plans

Motivation of the model – from String Theory

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



Motivation of the model – μ problem

MSSM superpotential:

$$\mathcal{W}_{\text{MSSM}} = \mu H_d H_u - h_{ij}^u (H_u Q_i) u_j^c - h_{ij}^d (H_d Q_i) d_j^c - h_{ij}^e (H_d L_i) e_j^c$$

In fact

- bilinear term $\mu H_d H_u$ can be present before SUSY is broken
- \rightarrow model definition at high scale M_X suggests $\mu \approx M_X$
- But from EWSB conditions

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

therefore $\mu \sim m_Z$ to allow $v = 174 \text{ GeV}$

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

Definition of the E_6 SSM – Gauge structure

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

Definition of the E_6 SSM

Supersymmetric gauge theory based on GUT gauge group E_6 , which is broken at the GUT scale

$$E_6 \rightarrow SU(3)_c \times SU(2)_L \times U(1)_Y \times U(1)_N$$

and $U(1)_N$ broken above EW scale

$$\begin{aligned} & SU(3)_c \times SU(2)_L \times U(1)_Y \times U(1)_N \\ \rightarrow & SU(3)_c \times SU(2)_L \times U(1)_Y \end{aligned}$$

Definition of the E_6 SSM – Matter content

Matter content

- 3 complete fundamental 27 representations $(\mathbf{27})_i$ of the E_6
- 2 Higgs like doublets H', \overline{H}' from $(\mathbf{27})', (\overline{\mathbf{27}})'$

⇒ model is anomaly free

Decomposition of $(\mathbf{27})_i$ under $SU(5) \times U(1)_N$:

$$(\mathbf{27})_i \rightarrow \underbrace{(\mathbf{10}, 1)_i + (\overline{\mathbf{5}}, 2)_i}_{Q_i, u_i^c, d_i^c, L_i, e_i^c} + \underbrace{(\overline{\mathbf{5}}, -3)_i + (\mathbf{5}, -2)_i}_{H_{1i}, H_{2i}, X_i, \overline{X}_i} + \underbrace{(\mathbf{1}, 5)_i}_{S_i} + \underbrace{(\mathbf{1}, 0)_i}_{n_i^c}$$

$Q_i, u_i^c, d_i^c, L_i, e_i^c, n_i^c$	Standard Model matter
S_i	$U(1)_N$ singlet fields
H_{1i}, H_{2i}	Higgs like fields
X_i, \overline{X}_i	exotic colored matter

H', \overline{H}'	extra Higgs like doublets
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Approximate the Superpotential:

- imposing a $Z_2^{B/L}$ (analog to R parity) and (approximate) Z_2^H symmetry to evade rapid proton decay and FCNC
- integrate out: n_i^c , H' , \overline{H}'
- keep dominant terms

\Rightarrow

$$\begin{aligned}\mathcal{W}_{E_6\text{SSM}} \approx & h_t(H_u Q)t^c + h_b(H_d Q)b^c + h_\tau(H_d L)\tau^c \\ & + \lambda_i S_3(H_{1i}H_{2i}) + \kappa_i S_3(X_i\overline{X}_i) \\ & (i = 1, 2, 3)\end{aligned}$$

Note: $\mu H_{1i}H_{2i}$ forbidden by $U(1)_N$ gauge symmetry

Constrained Exceptional Supersymmetric Standard Model

[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 :

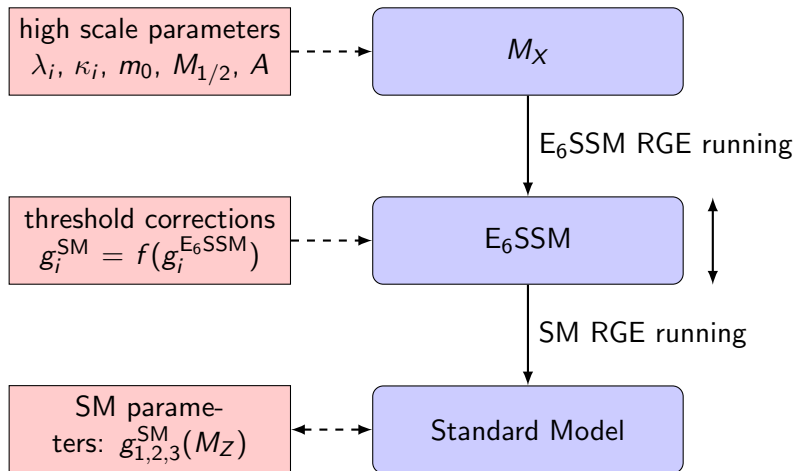
$$\begin{aligned}\text{scalar masses} &= m_0, \\ \text{Gaugino masses} &= M_{1/2}, \\ \text{trilinear couplings} &= A\end{aligned}$$

Input parameters for the constrained model:

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

Our aim: More precise particle masses

Why do we need threshold corrections?



Most important: Gauge coupling g_3 of $SU(3)_c$, since $\beta_3^{1L} = 0$

Lagrangian of full and effective theory:

$$\mathcal{L}^{\text{E}_6\text{SSM}} = \bar{q}(i\not{D} - m_q)q + \sum_{i=1}^2 \left(|D_\mu \tilde{q}_i|^2 - m_{\tilde{q}_i}^2 \tilde{q}_i^* \tilde{q}_i \right) + \dots$$

$$\mathcal{L}^{\text{SM}} = \hat{q}(i\hat{D} - \hat{m}_q)\hat{q} + \dots$$

where

$$D_\mu = \partial_\mu + ig_3 T^a A_\mu^a$$

$$\hat{D}_\mu = \partial_\mu + i\hat{g}_3 T^a \hat{A}_\mu^a$$

Relative field renormalization

Impose relative field renormalization between fields in full and effective theory

$$\hat{A}_\mu^a = \left(1 + \frac{1}{2}K_A\right) A_\mu^a$$
$$\hat{q} = \left(1 + \frac{1}{2}K_q\right) q$$

Matching procedure – Step 2

Matching condition

All one particle irreducible greens functions Γ (and their derivatives) in the full theory shall be equal to these of the effective theory at renormalization scale μ and momentum $p = 0$.

$$\Gamma_{q,\bar{q}}^{\text{E}_6\text{SSM}} = \Gamma_{q,\bar{q}}^{\text{SM}} \quad \Rightarrow \quad K_q = \left. \frac{\partial}{\partial p} \Gamma_{q,\bar{q}}^{\text{E}_6\text{SSM,heavy}} \right|_{p=0}$$

$$\Gamma_{A_\mu^a, A_\nu^b}^{\text{E}_6\text{SSM}} = \Gamma_{A_\mu^a, A_\nu^b}^{\text{SM}} \quad \Rightarrow \quad K_A = - \left. \frac{\partial}{\partial p^2} \Gamma_{A_\mu^a, A_\nu^b, T}^{\text{E}_6\text{SSM,heavy}} \right|_{p=0}$$

$$\Gamma_{A_\mu^a, q, \bar{q}}^{\text{E}_6\text{SSM}} = \Gamma_{A_\mu^a, q, \bar{q}}^{\text{SM}} \quad \Rightarrow \quad -g_3 \gamma^\mu T^a K_1 = \left. \Gamma_{A_\mu^a, q, \bar{q}}^{\text{E}_6\text{SSM,heavy}} \right|_{p=0}$$

$$\hat{g}_3 = g_3 \left(1 + K_1 - K_q - \frac{1}{2} K_A \right)$$

Matching procedure – Contributions

For example: Contributions from squarks \tilde{q}_1, \tilde{q}_2 :

$$i\Gamma_{q,\bar{q}}^{E_6SSM,heavy} = \sum_{i=1}^2 \text{Diagram 1}$$

$$i\Gamma_{A_\mu^a, A_\nu^b}^{E_6SSM,heavy} = \sum_{i=1}^2 \text{Diagram 2} + \text{Diagram 3}$$

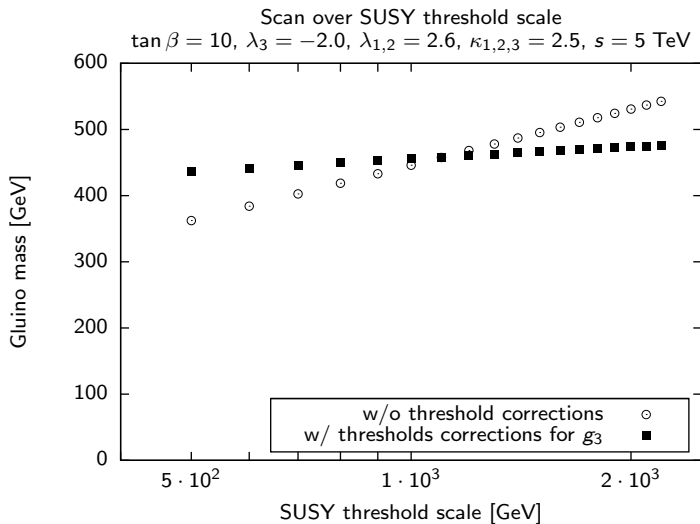
$$i\Gamma_{A_\mu^a, q, \bar{q}}^{E_6SSM,heavy} = \sum_{i=1}^2 \text{Diagram 4} + \text{Diagram 5}$$

Result when all non-Standard Model particles are integrated out:

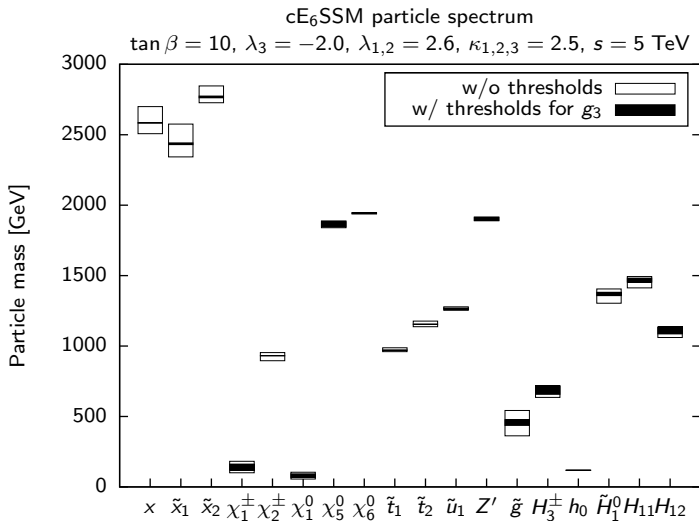
[J. L. Hall, Nucl.Phys.B178 (1981)]

$$g_3^{\text{E}_6\text{SSM},\overline{\text{DR}}} = g_3^{\text{SM},\overline{\text{MS}}} + \frac{g_3^3}{(4\pi)^2} \left\{ \frac{1}{2} - 2 \log \left(\frac{m_{\tilde{g}}}{\mu} \right) - \frac{1}{6} \sum_{\tilde{q}} \log \left(\frac{m_{\tilde{q}}}{\mu} \right) - \frac{2}{3} \sum_x \log \left(\frac{m_x}{\mu} \right) - \frac{1}{6} \sum_{\tilde{x}} \log \left(\frac{m_{\tilde{x}}}{\mu} \right) \right\}$$

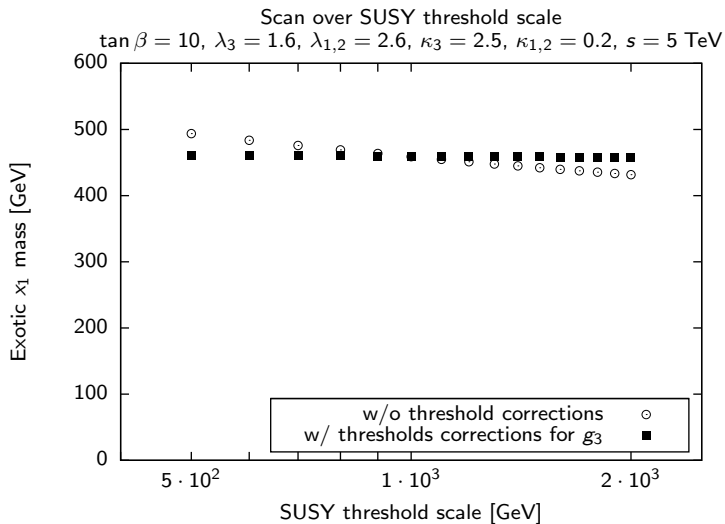
Matching scale dependence



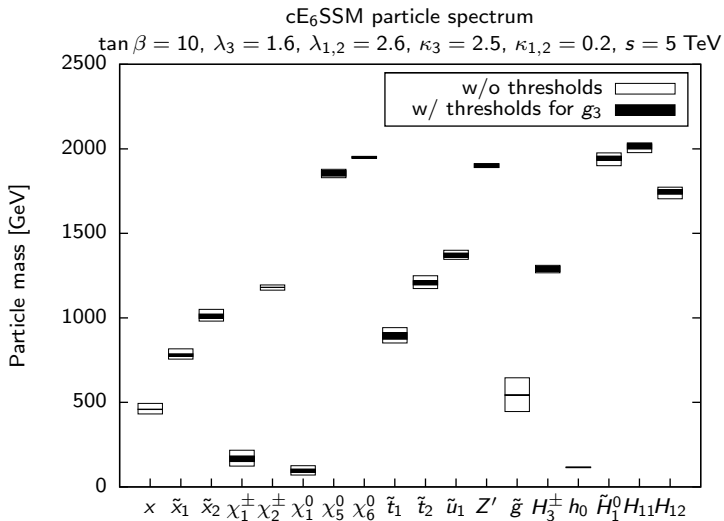
Matching scale dependence



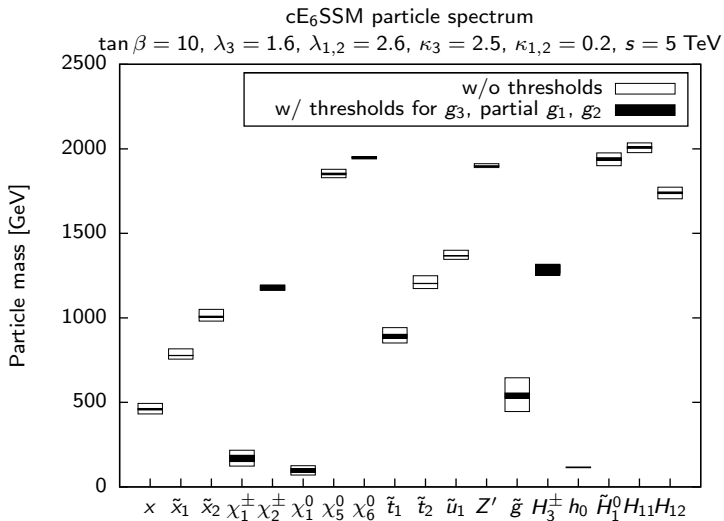
Matching scale dependence



Matching scale dependence



Matching scale dependence



Conclusions:

- First study of threshold effects in cE_6SSM
- Very split spectrum \rightarrow threshold corrections important
- threshold corrections reduce dependency of masses upon matching scale

Future plans:

- complete E_6SSM threshold corrections for g_1, g_2 (partly done already)
- E_6SSM threshold corrections for Yukawa couplings