The calculation of threshold corrections in the Exceptional Supersymmetric Standard Model (E_6SSM)

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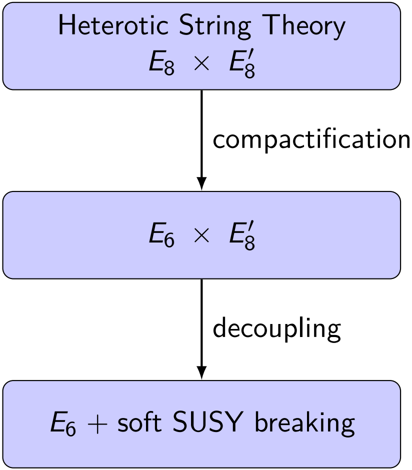
Outline

1. The Exceptional Supersymmetric Standard Model (E_6SSM)
   - 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:

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

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

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

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_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 GUT gauge group E_6, which is broken at the GUT scale

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

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

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

Definition of the E_6SSM – Matter content

Matter content

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

$\Rightarrow$ model is anomaly free

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

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

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

E_6SSM Superpotential

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

$\Rightarrow$

$$\begin{aligned}\mathcal{W}_{\mathrm{E_6SSM}} &\approx h_t(H_u Q)t^c + h_b(H_d Q)b^c + h_\tau(H_d L)\tau^c \\ &\quad +\lambda_i S_3(H_{1i}H_{2i}) + \kappa_i S_3(X_i \overline{X}_i) \\ &\quad (i = 1,2,3)\end{aligned}$$

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:

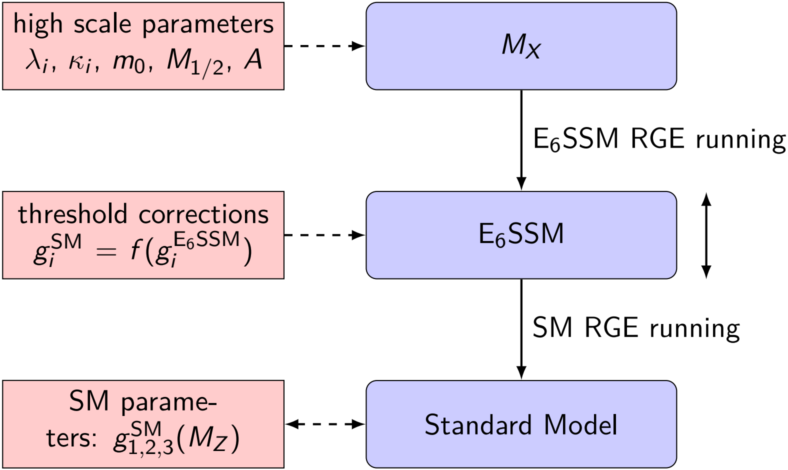
$$\begin{aligned} \text{scalar masses} &= m_0, \\ \text{Gaugino masses} &= M_{1/2}, \\ \text{trilinear couplings} &= A \end{aligned}$$

Input parameters for the constrained model:

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

Our aim: More precise particle masses

Why do we need threshold corrections?



Matching procedure

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

Lagrangian of full and effective theory:

$$\mathcal{L}^{\mathrm{E_6SSM}} = \bar{q}(\mathrm{i}\not{D} - m_q)q + \sum_{i=1}^{2}\left(|D_\mu \tilde{q}_i|^2 - m_{\tilde{q}_i}^2 \tilde{q}_i^* \tilde{q}_i\right) + \cdots$$
$$\mathcal{L}^{\mathrm{SM}} = \hat{\bar{q}}(\mathrm{i}\hat{\not{D}} - \hat{m}_q)\hat{q} + \cdots$$

where

$$D_\mu = \partial_\mu + \mathrm{i}g_3 T^a A_\mu^a$$
$$\hat{D}_\mu = \partial_\mu + \mathrm{i}\hat{g}_3 T^a \hat{A}_\mu^a$$

Matching procedure – Step 1

Relative field renormalization

Impose relative field renormalization between fields in full and effective theory

$$\hat{A}^a_\mu = \left(1 + \frac{1}{2} K_A\right) A^a_\mu$$

$$\hat{q} = \left(1 + \frac{1}{2} K_q\right) q$$

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 $p = 0$.

$$\Gamma^{E_6SSM}_{q,\bar{q}} = \Gamma^{SM}_{q,\bar{q}} \quad \Rightarrow \quad K_q = \frac{\partial}{\partial \not{p}} \Gamma^{E_6SSM,heavy}_{q,\bar{q}} \Big|_{p=0}$$

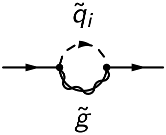
$$\Gamma^{E_6SSM}_{A^a_\mu, A^b_\nu} = \Gamma^{SM}_{A^a_\mu, A^b_\nu} \quad \Rightarrow \quad K_A = -\frac{\partial}{\partial p^2} \Gamma^{E_6SSM,heavy}_{A^a_\mu, A^b_\nu, T} \Big|_{p=0}$$

$$\Gamma^{E_6SSM}_{A^a_\mu, q, \bar{q}} = \Gamma^{SM}_{A^a_\mu, q, \bar{q}} \quad \Rightarrow \quad -g_3 \gamma^\mu T^a K_1 = \Gamma^{E_6SSM,heavy}_{A^a_\mu, q, \bar{q}} \Big|_{p=0}$$

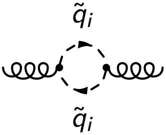
$$\boxed{\hat{g}_3 = g_3 \left(1 + K_1 - K_q - \frac{1}{2} K_A\right)}$$

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

$$i\Gamma^{E_6\text{SSM},\text{heavy}}_{q,\bar{q}} = \sum_{i=1}^{2}$$



$$i\Gamma^{E_6\text{SSM},\text{heavy}}_{A^a_\mu,A^b_\nu} = \sum_{i=1}^{2}$$



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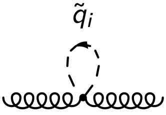
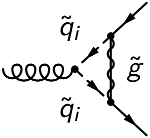


$$i\Gamma^{E_6\text{SSM},\text{heavy}}_{A^a_\mu,q,\bar{q}} = \sum_{i=1}^{2}$$



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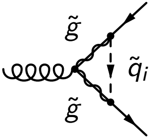


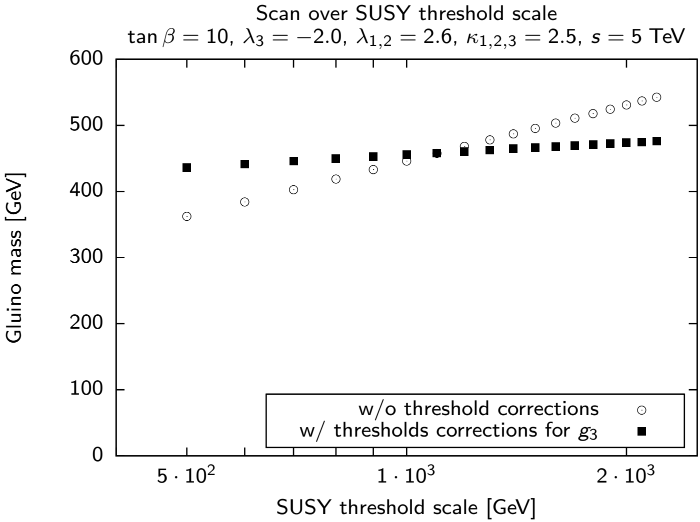
Matching procedure – Result

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

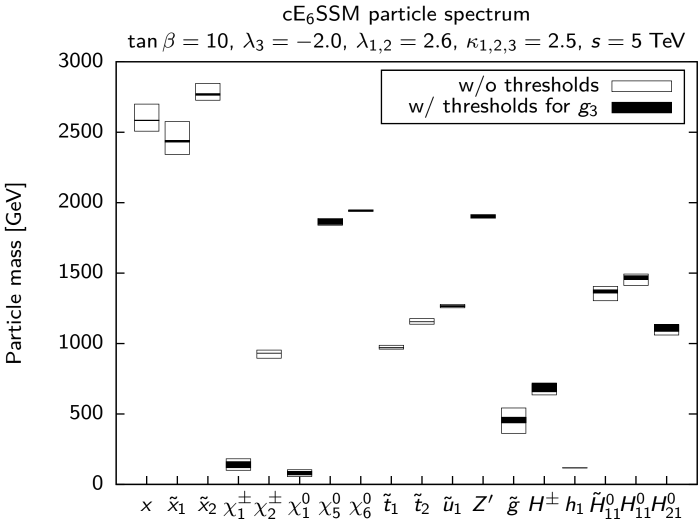
[J. L. Hall, Nucl.Phys.B178 (1981)]

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

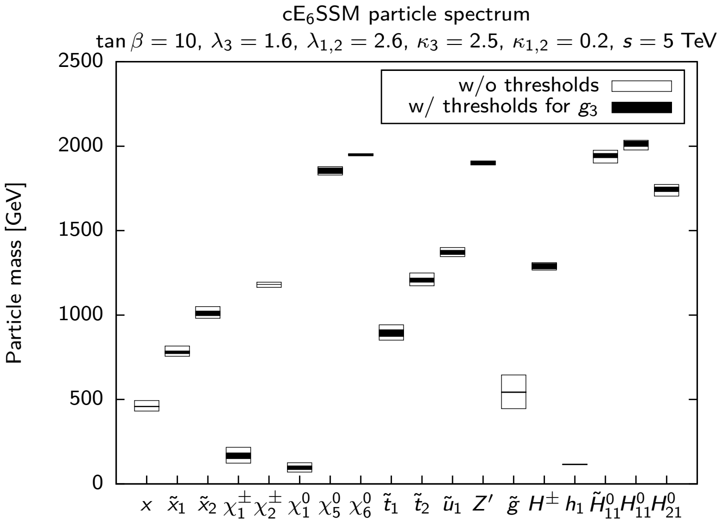
Matching scale dependence



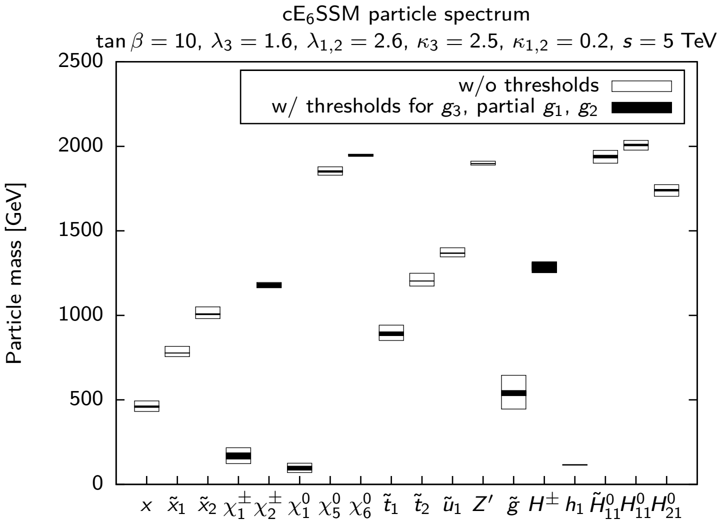
Matching scale dependence



Matching scale dependence



Matching scale dependence



Conclusions and Future plans

Conclusions:

- (c)E_6SSM is an interesting, well motivated model
- 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:

Increase the precision of the particle spectrum prediction

- complete E_6SSM threshold corrections for g_1, g_2 (partly done already)
- calculate E_6SSM threshold corrections for Yukawa couplings
- calculate 2-loop scalar masses
- add shifts to poles masses