5D MSSM at Two loop

Alan Cornell

Collaborators:Howeida M. Esmaeil, Mohammed Khojali,Aldo Deandrea and Ammar Abdalgabar

E-mail: acornell@uj.ac.za

June 15, 2022

Brief introduction

Minimal Supersymmetric Standard Model (MSSM) is an extension of the minimal SUSY to the SM. Since SUSY pairs fermions with bosons, every SM particle has a superpartner.

Table 1: *MSSM chiral supermultiplets*

Names	spin-0	spin-1/2	$SU(3)_C, SU(2)_L, U(1)_Y$
squarks, quarks (×3 families)	$(\tilde{u}_L \;\; \tilde{d}_L)$ $\tilde{u}_R^*$ $\tilde{d}_R^*$	$(u_L \;\; d_L)$ $u_R^\dagger$ $d_R^\dagger$	$(\,\mathbf{3},\, \mathbf{2}\,,\, \frac{1}{6})$ $(\,\overline{\mathbf{3}},\, \mathbf{1},\, -\frac{2}{3})$ $(\,\overline{\mathbf{3}},\, \mathbf{1},\, \frac{1}{3})$
sleptons, leptons (×3 families)	$(\tilde{\nu} \;\; \tilde{e}_L)$ $\tilde{e}_R^*$	$(\nu \;\; e_L)$ $e_R^\dagger$	$(\,\mathbf{1},\, \mathbf{2}\,,\, -\frac{1}{2})$ $(\,\mathbf{1},\, \mathbf{1},\, 1)$
Higgs, higgsinos	$(H_u^+ \;\; H_u^0)$ $(H_d^0 \;\; H_d^-)$	$(\tilde{H}_u^+ \;\; \tilde{H}_u^0)$ $(\tilde{H}_d^0 \;\; \tilde{H}_d^-)$	$(\,\mathbf{1},\, \mathbf{2}\,,\, +\frac{1}{2})$ $(\,\mathbf{1},\, \mathbf{2}\,,\, -\frac{1}{2})$

Table 2: *MSSM gauge supermultiplets*

Names	spin-1/2	spin-1	$SU(3)_C,\ SU(2)_L,\ U(1)_Y$
bino, B boson	$\tilde{B}^0$	B^0	$(\mathbf{1},\ \mathbf{1}\ ,\ 0)$
winos, W bosons	$\tilde{W}^{\pm}\quad \tilde{W}^0$	$W^{\pm}\quad W^0$	$(\mathbf{1},\ \mathbf{3}\ ,\ 0)$
gluino, gluon	$\tilde{g}$	g	$(\mathbf{8},\ \mathbf{1}\ ,\ 0)$

- The discovery of a SM-like scalar particle of mass $m_h \sim 125.5$ GeV and no direct evidence so far of superparticles has motivated renewed interest in non-minimal MSSM that can help to compellingly explain such results.
- One must still explain why stops are lighter than the other generations, consistent with colliders bounds. One such framework that can address this problem is the 5D MSSM.
- 5D theories are effective field theories with a cutoff and are defined as non-renormalisable as many parameters, such as gauge couplings, can be sensitive to this UV scale

5D MSSM models

- We define the 5D MSSM to be a field theory on 4D space-time, times an interval of length R in which the gauge fields and the Higgses (H_u, H_d) propagate into the fifth dimension and SM matter fields restricted to the brane $y = 0$
- The compactification produces a towers of new particle states for MSSM particle in 4D theory at $Q > 1/R$
- Note that NO contribution from Kaluza-Klein excited states of the fermions are on the brane

- In 5D, power law running for a sufficiently low R, generates at low energies a large enough A_t to explain the observed Higgs mass.
- One can localise different generations along the extra dimensions.
- It is an important to confirm the results and conclusions made at one loop that are sensitive to this scale are still consistent and under control at two loops.
- one might be concerned that one loop linear sensitivity to the cutoff behaving as ΛR does not result in terms of the form $(\Lambda R)^2$ at two-loop.
- We make use of RGEs

Sample of calculation of the two loop RGEs in 5D

The generic two-loop β functions can be written as:

$$\beta_{\tilde{g}}^{(2)} = 2\tilde{g}^5 C(V) Q - 2g^3 r^{-1} C(\Phi)\delta^i_j P^i_j;$$

$$\gamma_j^{(2)i} = [\tilde{y}^{\mathrm{imp}} \tilde{y}_{\mathrm{jmn}} + 2g^2 C(\Phi)\delta^p_j \delta^n_i] P^n_p$$
$$+ 2g^4 C(\Phi)\delta^j_i Q,$$

Where $r = \delta_{AA}$ is the dimension of the group.

- Two-loop corrections to the gauge coupling would be proportional to $(2\mu/M_c)^2$, coming from two-point diagrams with the exchange of heavy KK modes only.
- we have

$$P_H^H = P_{H'}^{H'} = 0 \quad P_{\Sigma^B}^{\Sigma^A} = 2g^2[T(H) + C(\Sigma)]\delta_{AB} = g^2 Q \delta_{AB}$$

- The leading contribution to $\beta_{\tilde{g}}^{(2)}$ vanishes.This cancellation reflects the fact that a model with $N = 2SUSY$ has to be renormalized only at the one-loop level

- The sub leading correction, proportional to $2\mu/M_c$,does not vanish because the underlying $N=2$ SUSY is broken by the the interaction of the field in the loops, it can be written A:

$$\beta_{\tilde{g}}^{(2)} = 2\tilde{g}^5 C(V)\{3[T(H)+T(H^{'})]+T(f)+C(\Sigma)-9C(V)\}$$
$$-2g^3 r^{-1} C(H)\left[(4-6)g^2 C(H)d(H)+\frac{1}{2}y^{Hff'}y_{Hff'}\right.$$
$$\left.+(H\leftrightarrow H)\right]-2g^3 C(\Sigma)2g^2[2T(H)-C(\Sigma)]$$
$$-2g^3 r^{-1} C(f)\left[\frac{1}{2}y^{fkl}y_{fkl}-2g^2 C(f)d(f)\right],$$

where $d(\Phi)$ is the dimension of the Φ representation and f stands for the chiral fermions.

- The beta functions for gauge and Yukawa couplings were then calculated.

Typical scales of the models

- It is useful to set the mass and energy scales, this leads us to fix the gauge coupling unification scale and the scale of the cut off, where the gauge couplings hit a Landau pole

$$\frac{1}{R} \sim 10 \text{ TeV} \;, \;\; M_{GUT} \sim 300 \text{ TeV} \;, \;\; \Lambda \sim 1,000 \text{ TeV}.$$

- To allow for the correct Higgs mass $m_h = 125$ GeV, the electroweak parameters should be in the range

$$\tan\beta \subset (5, 30), \quad \mu \leq 1\text{TeV},$$

- We specify a set of boundary conditions.
- Simply specify all boundary conditions at the same scale, which we took to be t=3, or $Q = 10^3$ GeV (where we define $t = \ln(Q^2/m_Z^2)$).

- We assume supersymmetry breaking occurs at the unification scale, which is found by finding the scale at which $g_1 = g_2 = g_3$, which is lowered compared to the 4D MSSM, by the effects of the compactification as picture in figure below.

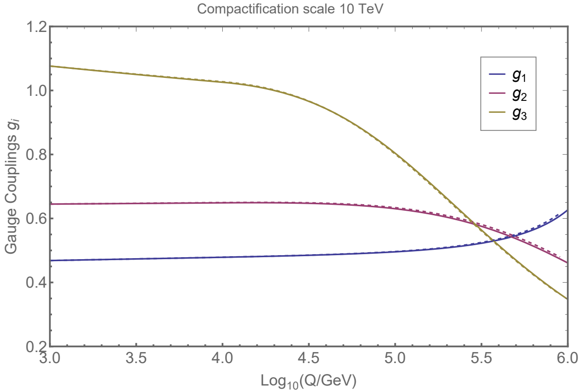

Figure 1: *Running of the inverse fine structure constants $\alpha_i^{-1}(Q)$, for three different models with compactification scales 10 TeV as a function of $\mathrm{Log}_{10}(Q/GeV)$.*

We specify the value of the gluino mass, $M_3(Q)$, at $Q = 10^3$ GeV. We then find the bino and wino soft masses M_1 and M_2 such that all gaugino masses $M_1 = M_2 = M_3$ at the GUT scale. see below.

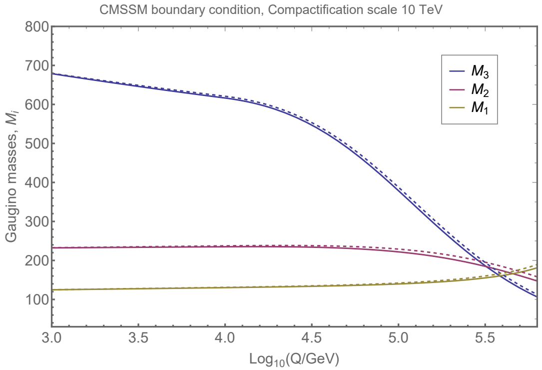

Figure 2: *Running of the gaugino masses $M_i(Q)$, with compactification scales 10 TeV, as a function of $Log_{10}(Q/GeV)$.*

We take the trilinear soft breaking terms, $A_{u/d/e}$, to vanish at the unification scale, as shown in figure below.

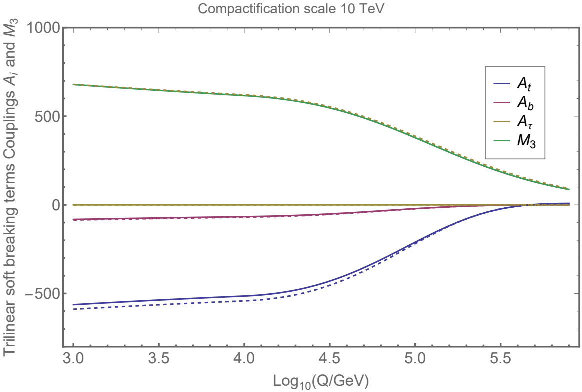

Figure 3: *trilinear couplings $A_i(Q)$, with compactification scales 10 TeV, as a function of $Log_{10}(Q/GeV)$.*

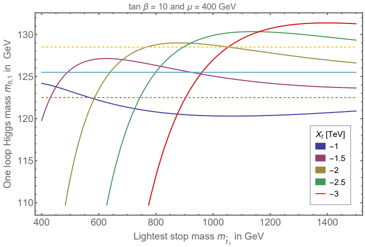

Figure 4: In the left panel one-loop Higgs mass versus the lightest stop mass for representative values of $X_t = A_t - \mu \cot \beta$ corresponding to those of the 5D MSSM. In the right panel two-loop Higgs mass for different values of the stop mass.

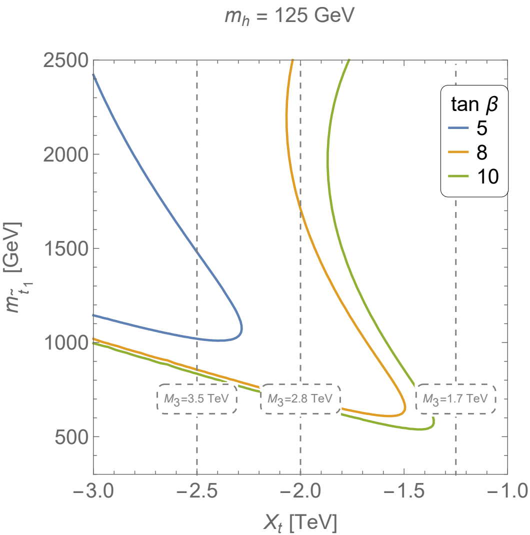

Figure 5: Contours of the lightest Higgs mass $m_h = 125$ GeV in the plane $(m_{\tilde{t}_1}, X_t)$ for various values of $\tan\beta$ for two loop. The dashed lines represent the gluino mass for values of X_t.

Conclusion

- In this talk we explored the five dimensional MSSM at two loops.
- We computed the full two loop RGE's for all supersymmetric and soft term parameters
- Compared those results to those found at one loop.
- Our results confirm that a large A_t may be generated at low energies from a UV boundary condition where A_t is vanishing, through power-law running.

THANK YOU