Large A_t Without the Desert

Based on A. Abdalgabar, A. S. Cornell, A. Deandrea and M. McGarrie. JHEP **1407** (2014) 158

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February 12, 2015

Outline

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- RGEs for 5D MSSM
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Brief introduction

- The discovery of a scalar particle of mass $m_h \sim 126$ GeV in 2012, consistent with the SM Higgs boson

- One-loop Higgs mass is given by

$$m_{h,1}^2 \simeq m_z^2 \cos^2 2\beta + \frac{3}{4\pi^2} \frac{m_t^4}{v_{ew}^2} \left[\ln \frac{M_S^2}{m_t^2} + \frac{X_t^2}{M_S^2} \left(1 - \frac{X_t^2}{12 M_S^2} \right) \right]$$

$$(126\, GeV)^2 = (91\, GeV)^2 + (81\, GeV)^2$$

- MSSM implies either heavy stops or large $X_t = A_t - \mu \cot\beta$

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 $y = 0$ brane
- The compactifications produce a towers of new particle states for MSSM particle in 4D theory at $Q > 1/R$
- No contribution from Kaluza-Klein excited states of the fermions on the brane
- We make use of RGEs

RGEs for 5D MSSM

The one loop beta function for the gauge couplings and gaugino soft masses if $t > \log(1/R)/\log(10)$ are given by

$$
\begin{aligned}
16\pi^2 \frac{dg_i}{dt} &= b^i_{4D} g_i^3 + b^i_{5D} g_i^3 (S(t) - 1) \,, \\
16\pi^2 \frac{dM_i}{dt} &= 2 b^i_{4D} M_i g_i^2 + 2 b^i_{5D} M_i g_i^2 (S(t) - 1),
\end{aligned}
$$

where

$$
\begin{aligned}
S(t) &= (m_Z R) e^{t(\log(10) - \log(m_Z))}, \\
b^i_{4D} &= (33/5, 1, -3), \\
b^i_{5D} &= (6/5, -2, -6).
\end{aligned}
$$

Yukawa couplings

The five dimensional contribution are given by

$$\begin{aligned}
\beta_{Y_u} &= Y_u\left[\left(6Y_u^\dagger Y_u + 2Y_d^\dagger Y_d\right) - \left(\frac{34}{30}g_1^2 + \frac{9}{2}g_2^2 + \frac{32}{3}g_3^2\right)\right] \\
\beta_{Y_d} &= Y_d\left[(6Y_d^\dagger Y_d + 2Y_u^\dagger Y_u) - \left(\frac{19}{30}g_1^2 + \frac{9}{2}g_2^2 + \frac{32}{3}g_3^2\right)\right] \\
\beta_{Y_e} &= Y_e\left[6Y_e^\dagger Y_e - \left(\frac{33}{10}g_1^2 + \frac{9}{2}g_2^2\right)\right].
\end{aligned}$$

Trilinear soft breaking parameters

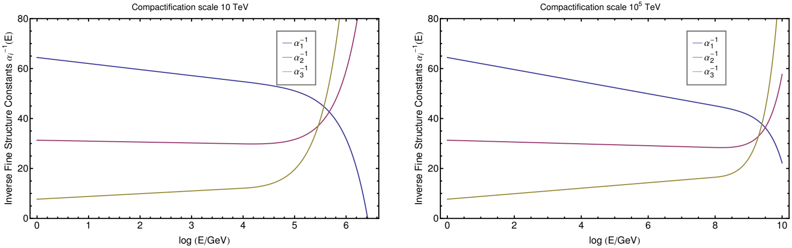
In the 5D MSSM these are given by:

$$\beta_{A_u} = A_u\left(\left(18Y_u^\dagger Y_u + 2Y_d^\dagger Y_d\right) - \left(\frac{34}{30}g_1^2 + \frac{9}{2}g_2^2 + \frac{32}{3}g_3^2\right)\right)$$
$$+4A_d Y_d^\dagger Y_u + Y_u\left(\frac{34}{15}g_1^2 M_1 + 9g_2^2 M_2 + \frac{64}{3}g_3^2 M_3\right)$$
$$\beta_{A_d} = A_d\left(\left(18Y_d^\dagger Y_d + 2Y_u^\dagger Y_u\right) - \left(\frac{19}{30}g_1^2 + \frac{9}{2}g_2^2 + \frac{32}{3}g_3^2\right)\right)$$
$$+4A_u Y_u^\dagger Y_d + 2A_e Y_e^\dagger Y_d + Y_d\left(\frac{19}{15}g_1^2 M_1 + 9g_2^2 M_2 + \frac{64}{3}g_3^2 M_3\right)$$
$$\beta_{A_e} = A_e\left(18Y_e^\dagger Y_e - \left(\frac{33}{10}g_1^2 + \frac{9}{2}g_2^2\right)\right) + Y_e\left(\frac{33}{5}g_1^2 M_1 + 9g_2^2 M_2\right)$$
$$+6A_d Y_d^\dagger Y_e.$$

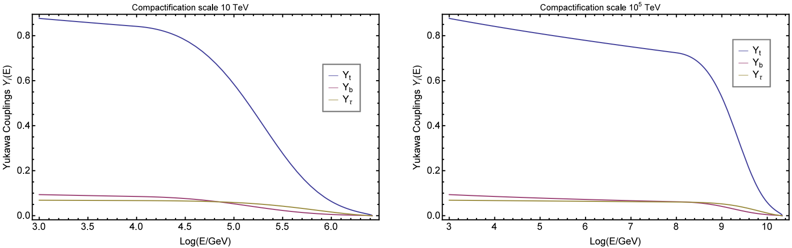
Regarding the breaking of SUSY. We do, however, make some minimal specifications:

- We take as inputs the Yukawa and gauge couplings at the SUSY scale, 1 TeV.
- We will assume SUSY breaking occurs at the unification scale, which is found by finding the scale at which $g_1 = g_2$.
- We specify the value of the gluino mass, M_3 at 1 TeV.
- We take the trilinear soft breaking terms, $A_{u/d/e}$, to vanish at the unification scale.

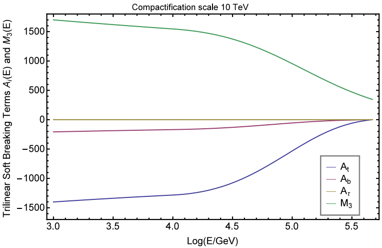
Results and Discussions

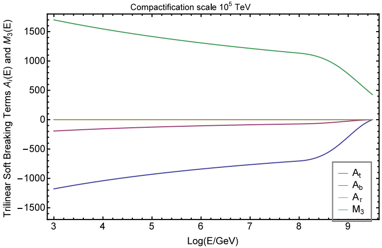


The key feature is that with a larger compactification radius the unification scale can be significantly lowered, lowering the desert of scales between the EW scale and unification.

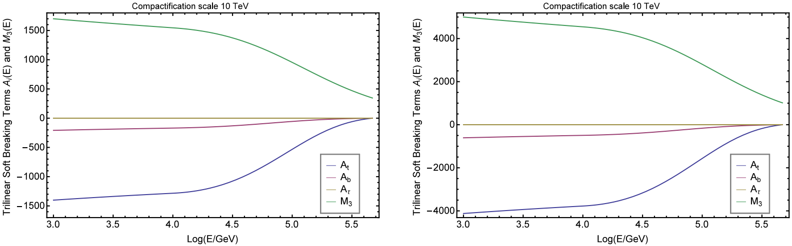


We also specify the Yukawa coupling RGEs boundary conditions at 1 TeV, which interestingly appears to vanish when evolved to the unification scale

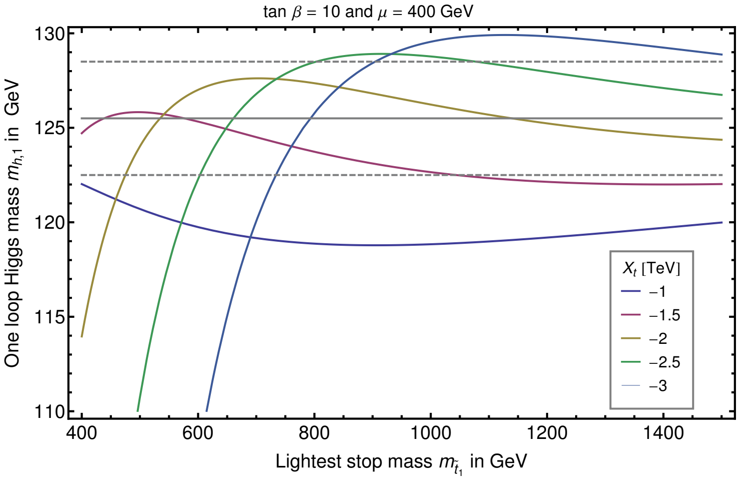




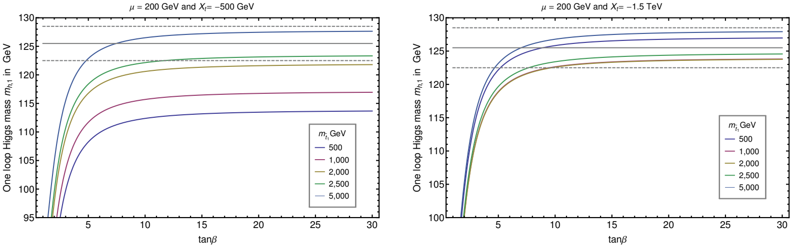
We see that by increasing the compactificaton radius one can increase the size of the trilinear soft breaking term.



Here we show that after a reasonable period of RG evolution the A_t mimics the magnitude of the gluino mass, at $1/R \sim 10$ TeV, such that at low scales $|A_t| \sim M_3$.



A plot of the one loop Higgs mass versus the lightest stop mass for representative values of $X_t = A_t - \mu \cot \beta$.



A plot of the one loop Higgs mass versus $\tan\beta$ for different values of the stop mass, for $X_t = A_t - \mu \cot\beta$ of -500 GeV (left panel) and -1.5 TeV (right panel).

Conclusions

- We have explored how 5D extension of the MSSM may generate large A_t to achieve the observed Higgs mass and have sub-TeV stops, perhaps observable at the LHC.
- We computed the full one-loop RGEs for all supersymmetric and soft breaking parameters.
- We find that Yukawa couplings may be made to unify and approximately vanish at the unification scale.
- We find that the magnitude of A_t follows closely that of the magnitude of M_3 and increases as the compactification scale decreases.

Acknowledgements

I would like to thank the following:

- The organizers for the invitation.
- My collaborators A. Deandrea and M. McGarrie.

THANK YOU