Natural SUSY and Unification in 5D

presented by Alan S. Cornell
National Institute for Theoretical Physics;
School of Physics, University of the Witwatersrand
South Africa

NITheP
National Institute for
Theoretical Physics

This talk is based on:

- A. Abdalgabar, A. S. Cornell, A. Deandrea and M. McGarrie, "Natural Supersymmetry and Unification in Five Dimensions", JHEP **1601**, 083 (2016) arXiv:1504.07749 [hep-ph].

- A. Abdalgabar, A. S. Cornell, A. Deandrea and M. McGarrie, "Large A_t Without the Desert", JHEP **1407**, 158 (2014) arXiv:1405.1038 [hep-ph].

Introduction

Discovery of the SM Higgs and no direct evidence for sparticles has renewed interest in non-minimal extensions of the SSM.

Within the MSSM, for the lightest CP-even neutral scalar to be this discovered scalar requires either

- multi-TeV stops (disfavoured from naturalness),
- an enhancement to the tree-level Higgs mass,
- or near max. mixing where $|A_t(M_z)| \gtrsim 1$ TeV.

Few models compellingly achieve a large enough A_t, if A_t is to vanish at some initial SUSY breaking scale.

Even if we have such a large A_t, why are stops lighter than their 1^{st} and 2^{nd} gen. counterparts?

One such framework that can address both problems is a *five dimensional*-SSM.

In 5D, power law running for a sufficiently low R, generates a large enough A_t to explain the observed Higgs mass.

Spatially localising different generations along the XD(s), one can explain why the 3^{rd} gen. can be consistently lighter.

5D theories are effective theories with a cutoff and are defined as non-renormalisable,
as many parameters can be sensitive to this UV scale.

So we require that SUSY is softly broken,
the superpotential is renormalisable and that the gauge couplings *unify* in the 5D description
with large enough XD to make it pheno. relevant.

Ie, we require a $1/R \sim 1$ to 10^3 TeV scale XD.

Such criteria rule out certain models, such as flat XD models where 1^{st} and 2^{nd} gen. are in the bulk, with 3^{rd} gen. either in the bulk or on a brane

Model 1

A TeV scale SSM in which the gauge coupling is precisely unified was proposed by Delgado *et al.*

The key idea is to add two new hypermultiplets $F^{\pm}$ which are singlets under $SU(3)_c \times SU(2)_L$ and charged under $U(1)_Y$ with $Y_{F^{\pm}} = \pm 1$.

The SSM chiral fermions are located on a boundary and in the 5D picture do not have KK modes.

The SSM Higgs chiral multiplets live in the bulk.

The gauge fields and the additional states also live in the bulk.

Model 2

We will also explore our own model in which the 3^{rd} generation of superfields lives in the bulk.

These new states modify the beta function coefficient b_1 and lead to precision unification at one-loop.

The superpotential for both models is given by

$$\begin{aligned} W &= Y_u\, \hat{u}\, \epsilon_{ij} \hat{q}^i\, \hat{H}_u^j - Y_d\, \hat{d}\, \epsilon_{ij} \hat{q}^i\, \hat{H}_d^j - Y_e\, \hat{e}\, \epsilon_{ij} \hat{l}^i\, \hat{H}_d^j \\ & \quad + \mu H_u H_d + \acute{\mu} F^- F^+ \ . \end{aligned}$$

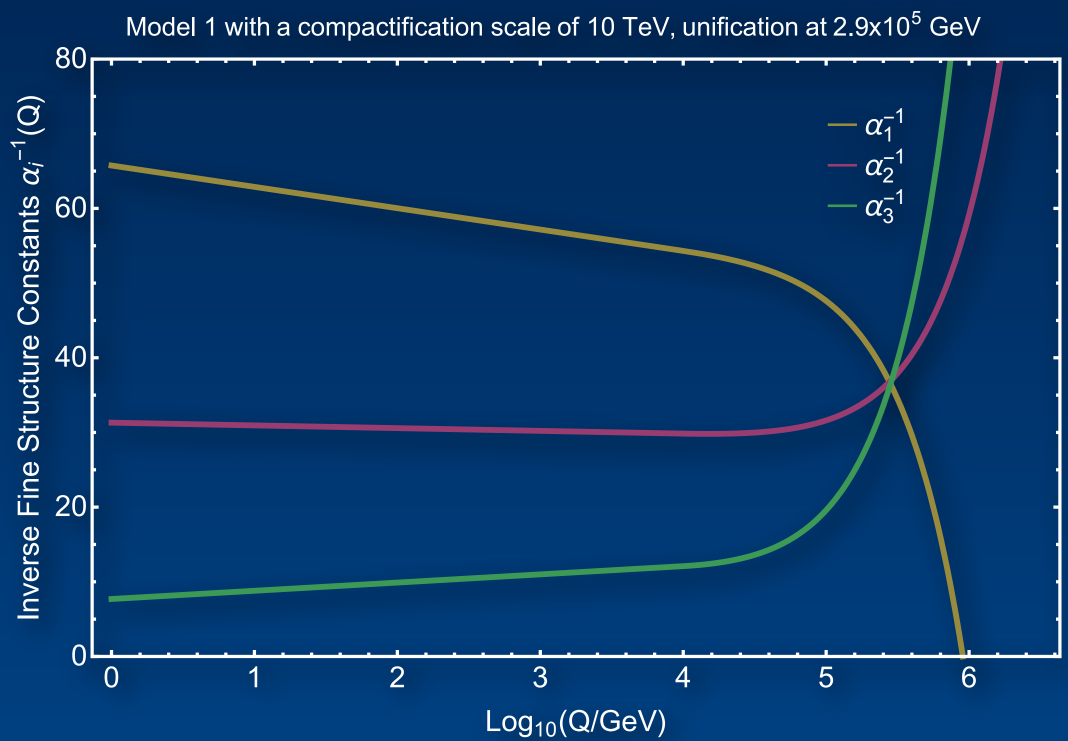
Model 3

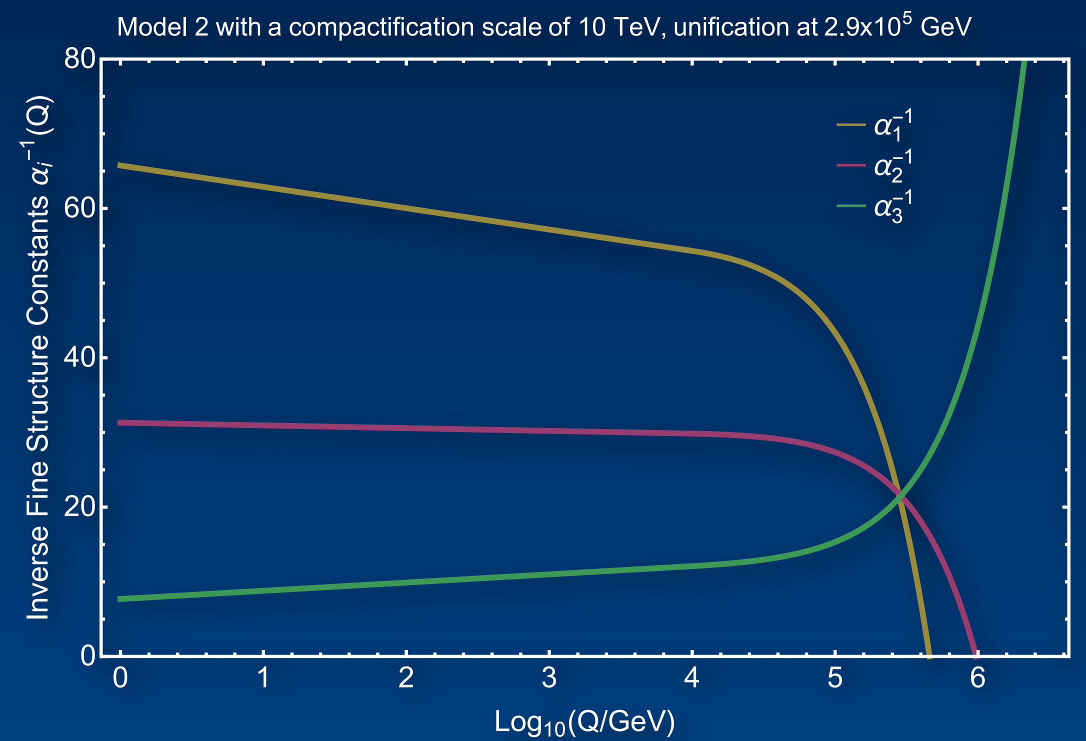
NB the additional matter of the $5D$ MSSM-UED means that all β-fns' coefficients are positive.

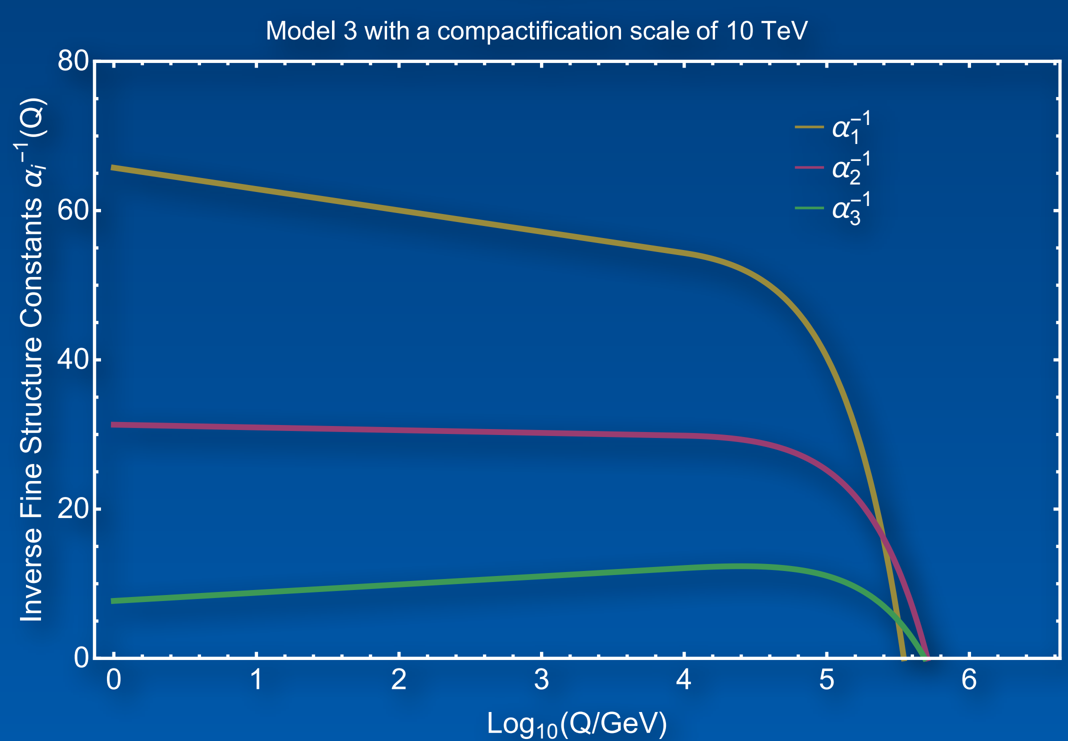
This forces $1/R \gtrsim 10^{10}$ GeV for unification to still be possible.

As such, low scale (supersymmetric) XDs therefore require that most of the MSSM matter does not live in the bulk.

So we can also consider the case where only the 3^{rd} gen. lives in the brane.







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

NB the effective cutoff of a 5D theory is defined as the scale at which some param. hits a Landau pole.

Typical scales of the models

We wish for a large XD, which then leads us to fix the gauge coupling unification scale and the scale of the cut off, where the gauge couplings hit a Landau pole:

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

Although they differ in magnitude, this is natural in that fixing any one of these determines the other two.

Next we wish for a gluino mass above collider exclusions and to determine $m_h = 125$ GeV from a sizeable A_t. We find

$$M_3 = 900 \text{ GeV leads to } A_t \sim -700 \text{ GeV} \quad ,$$
$$M_3 = 1700 \text{ GeV leads to } A_t \sim -1250 \text{ GeV}.$$

Strong exclusion limits on the gluino arise from ATLAS and CMS null searches for jets plus missing energy, although this can be lowered if one wishes to also include R-parity violation with our models.

Conversely, allowing for an upper bound on the top trilinear coupling, from considering metastability of the EW vac,

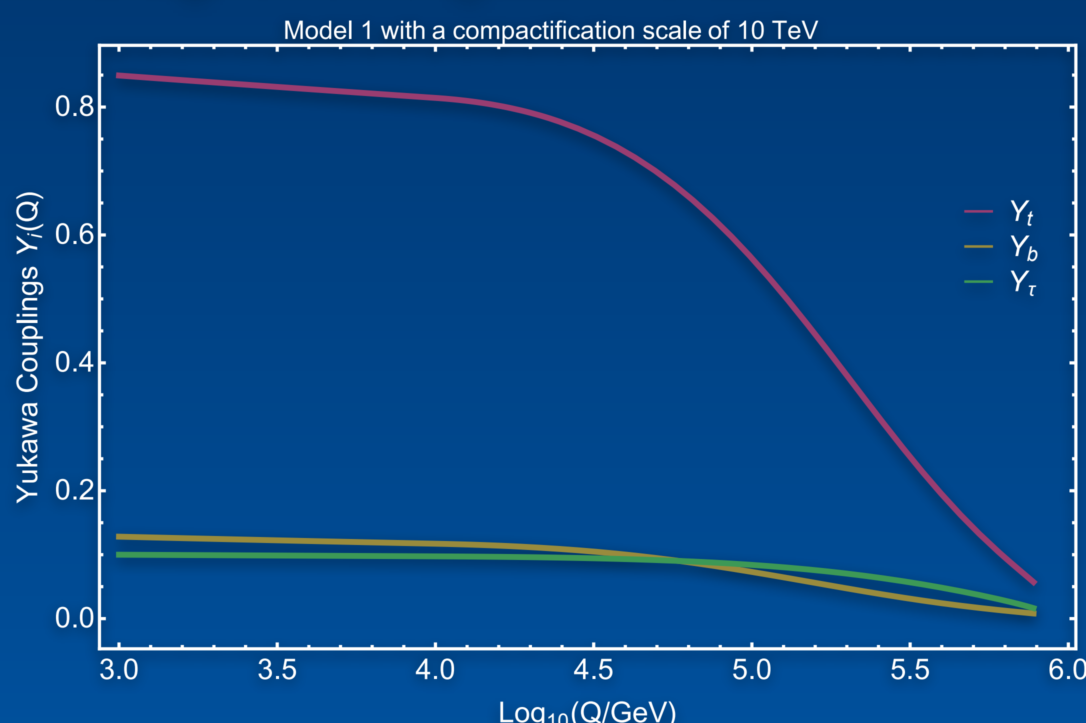
$$A_t = -2 \text{ TeV leads to } M_3 \sim 2.77 \text{ TeV}$$
$$\text{and } \; A_t = -2.5 \text{ TeV leads to } M_3 \sim 3.5 \text{ TeV}.$$

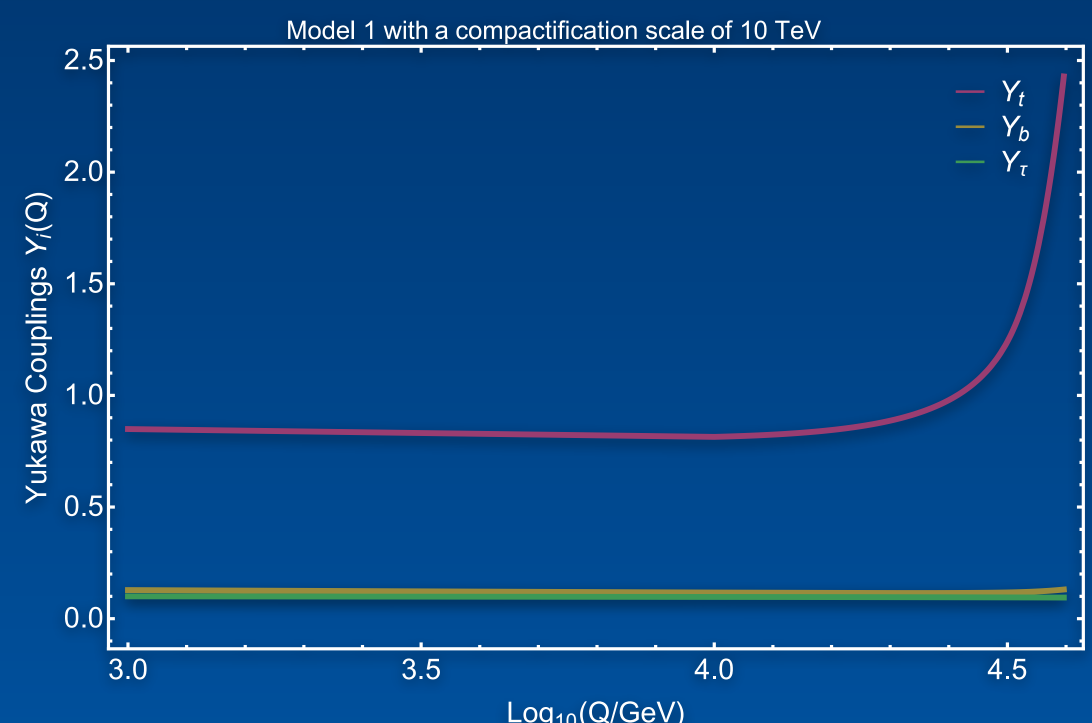
To allow for the correct Higgs mass $m_h = 125$ GeV, the electroweak parameters should be in the range

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

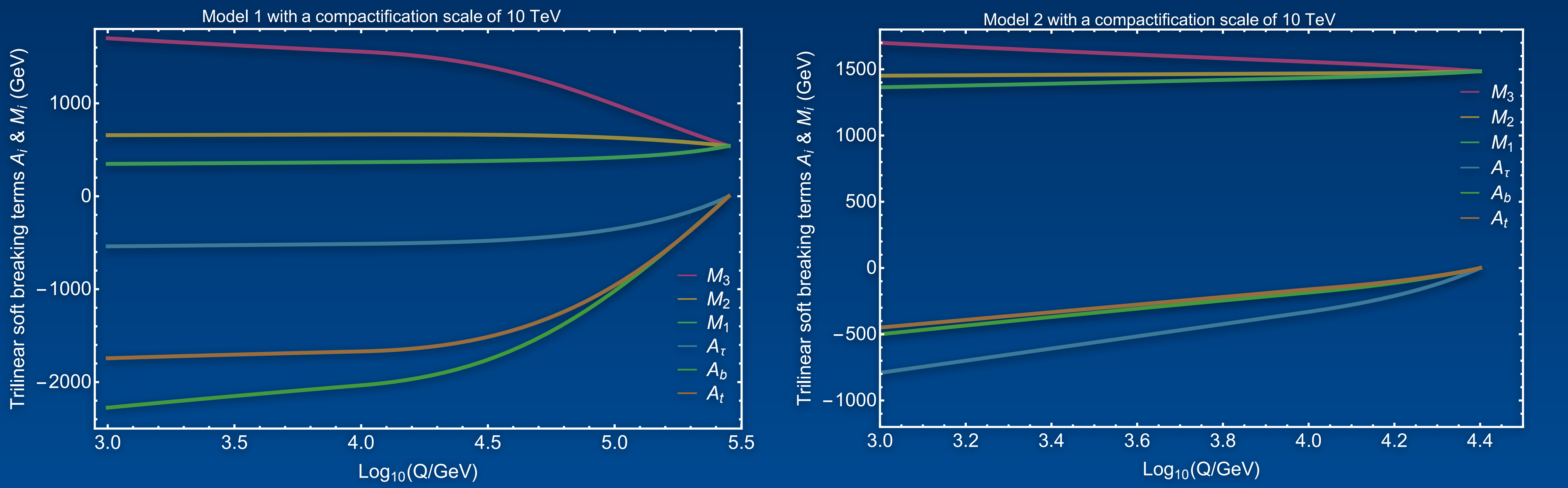
represented in the plot at the end.

We do not expect $\tan\beta$ to be much larger, due to $B_s \to X_s\gamma$ flavour constraints and μ is bounded by naturalness considerations of the RGEs on the Higgs tadpole equations.





Running of the Yukawas, for the different models with compactification scales 10 TeV. The top Yukawa typically hits a Landau pole before the GUT scale when the 3^{rd} gen. matter is in the bulk.



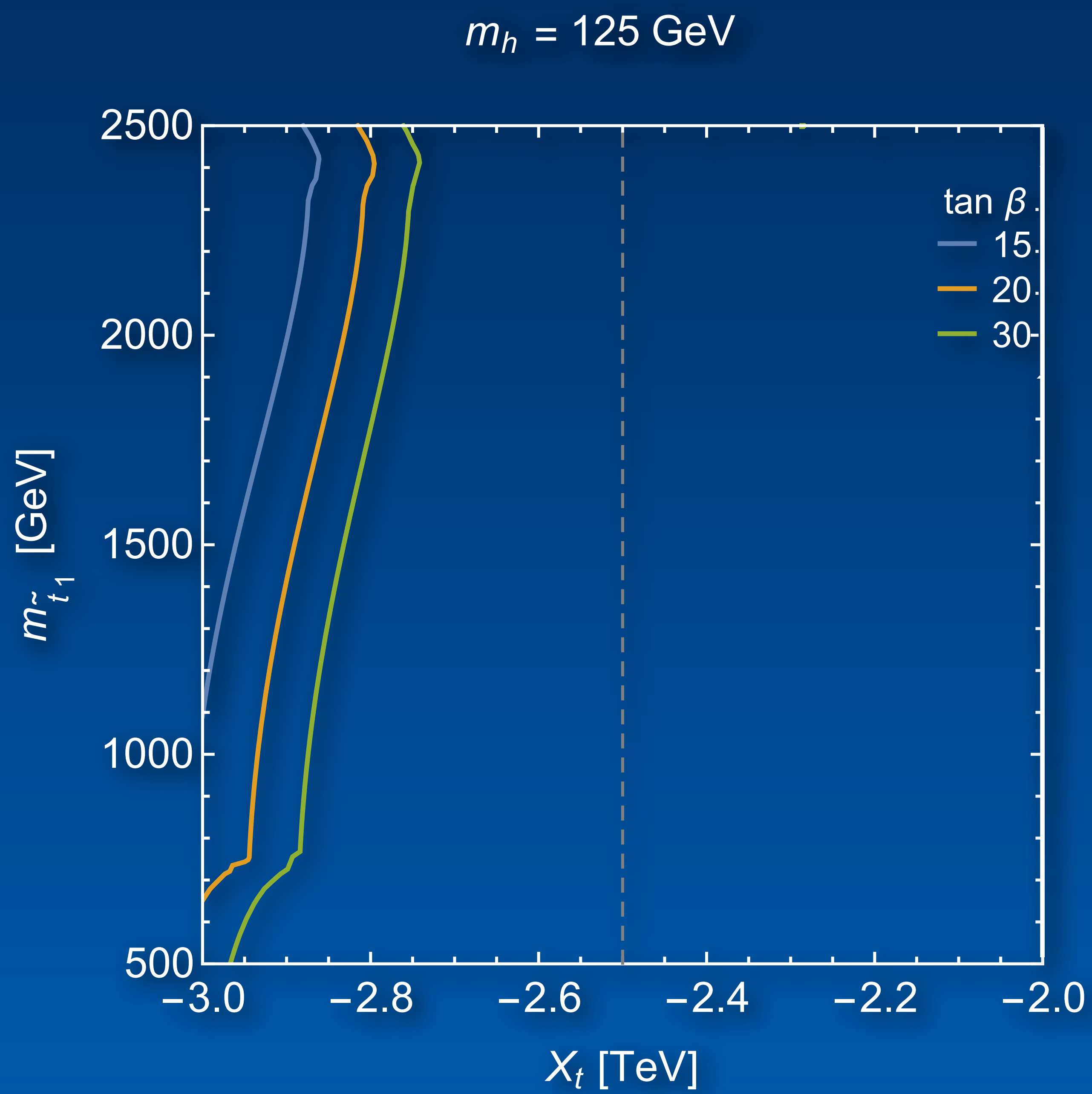
Running of the gaugino masses and trilinear couplings, for two models with compactification scales 10 TeV, as a function of $Log_{10}(Q/GeV)$

A large A_t term

Our **model 1** does not geometrically explain why the 1^{st} and 2^{nd} gen. might be much heavier than the 3^{rd}, but it does allow for a large A_t term generated entirely through RGE evolution, and this can still allow for stops much below 2 TeV and still obtain the correct Higgs mass.

Therefore for **model 1**, we do not yet offer an explanation of the source of SUSY breaking.

The Higgs mass



The dashed gray line represents a sample gluino mass ($M_3 = 3.5$ TeV) for the corresp. value of X_t. Stop masses below 2 TeV can be obtained in our model due to the TeV-scale A_t term.

$$X_t = A_t - \mu \cot \beta$$

A realistic and precise calculation of m_H in SUSY requires the inclusion of two-loops. Yet, to have a rough intuition concerning a large A_t from our setup, the leading one-loop self-energy contrib. to the lightest CP even Higgs is

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

where $M_S^2 = m_{\tilde{t}_1} m_{\tilde{t}_2}$.

This allows to understand why a model with large A_t values can help increasing the value of the m_H.

Conclusions

- In this talk we explored various 5D extensions of the SSM that unify, with an inverse radius of the extra dimension of roughly a 10 TeV scale.

- Such models have features such as additional Z', W' and G' bosons in the $1 - 10$ TeV range and achieve the correct m_H:
  $\Rightarrow$ with a rel. nat. sparticle spec. for model 1
  $\Rightarrow$ while for model 2 this spectrum is heavier