Split Supersymmetry and the infrared fixed point of the top Yukawa coupling

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- Introduction to split-supersymmetry
- Infra-red fixed point of top Yukawa coupling
- Numerical results
- Conclusion

Naturalness criterion - guiding principle in the formulation of (M)SSM.

Successful implementation of the gauge coupling unification

LSP emerges as a viable dark matter candidate

Can one abandon the principle of naturalness and maintain the nice phenomenological aspects of the SSM at the same time ?

Is it possible that SUSY is broken in the SSM at very high energy scales ?

Recently advanced landscape paradigm - enormous no. of long-lived metastable vacuua.

All the scalars lie far above the electroweak scale. Except one finetuned light Higgs

Successful unification of gauge couplings of the SSM can be retained

Free of many of the undesirable features - flavor problem, fast proton decay via dim. 5 operators, a tightly constrained mass of the lightest Higgs .....

Gauginos and Higgsinos of this theory chosen to lie near the TeV scale - a stable LSP, gauge coupling unification.

Split-supersymmetry

N. Arkani-Hamed, S. Dimopoulos, hep-th/0405159;
G.F. Giudice, A. Romanino, Nucl. Phys. **B699**, 65(2004).

Various theoretical and phenomenological aspects discussed in several recent works.

A. Pierce, Phys. Rev. D**70**, 075006 (2004)
A. Arvanitaki et al. hep-ph/0406034
N. Arkani-Hamed et al., hep-ph/0409232
B. Mukhopadhyaya, S. Sengupta, hep-th/0407225
W. Kilian et al., hep-ph/0408088
S.K. Gupta, P. Konar, B. Mukhopadhyaya, Phys. Lett. **B606**, 384(2005).
K.S. Babu et al.,hep-ph/0501079
K. Cheung, C-W. Chiang, hep-ph/0501265
A. Ibarra, hep-ph/0503160
E. Dudas and S. K. Vempati, hep-th/0506172

$\vdots$

Parameters of minimal split SUSY

Common mass for the heavy scalars : $\tilde{m}$

tan β - defines the combination of H_u and H_d fields which remains light

Higgsino mass parameter- μ

gluino mass $m_{\tilde{g}}$

Grand unification scale M_{GUT} and the unified value of the gauge coupling strength α_G.

Gluinos are long-lived due to the large value of the squark masses which mediate their decays

(Talk by P. Slavich)

Negative searches for heavy isotopes $\Rightarrow \tilde{m} \lesssim 10^{13}$ GeV for 1 TeV gluino

In collider : displaced vertices

Once produced long-lived gluino hadronize into color singlet state

At LHC neutralino and charginos produced through gauge boson interactions

(Talk by P. Richardson)

Infra-red fixed point of Y_t

Fixed point behaviour of Y_t in MSSM

At the one-loop level :

$$Y_t(0) = \frac{Y_t(t)}{E(t) D_0}$$

with

$$D_0 = 1 - 6 Y_t(t) \frac{F(t)}{E(t)}$$

$t = 2 \ln(M_{GUT}/Q), \quad Y_t = \lambda_t^2/(4\pi)^2$

$$E(t) = (1 + \beta_3 t)^{16/3b_3} (1 + \beta_2 t)^{3/b_2} (1 + \beta_1 t)^{13/9b_1}$$

$$F(t) = \int_0^t E(t') dt'.$$

$\beta_i = b_i \alpha_G/(4\pi) \qquad (b_1, b_2, b_3) = (33/5,\ 1,\ \text{-}3)$

A fixed point in the top Yukawa coupling corresponds to

$$Y_t^f(t) = E(t)/6F(t)$$

The structure of split SUSY

Effective theory in which the scalars (apart from a fine-tuned light Higgs) are integrated out

Spectrum contains :

higgsino $\tilde{H}_{u,d}$, gluino $\tilde{g}$, Wino $\tilde{W}$, Bino $\tilde{B}$

SM particles with one Higgs doublet h

$h = -cos\beta\epsilon H_d^* + sin\beta H_u$

fine-tuned to have small mass term

Effective Lagrangian

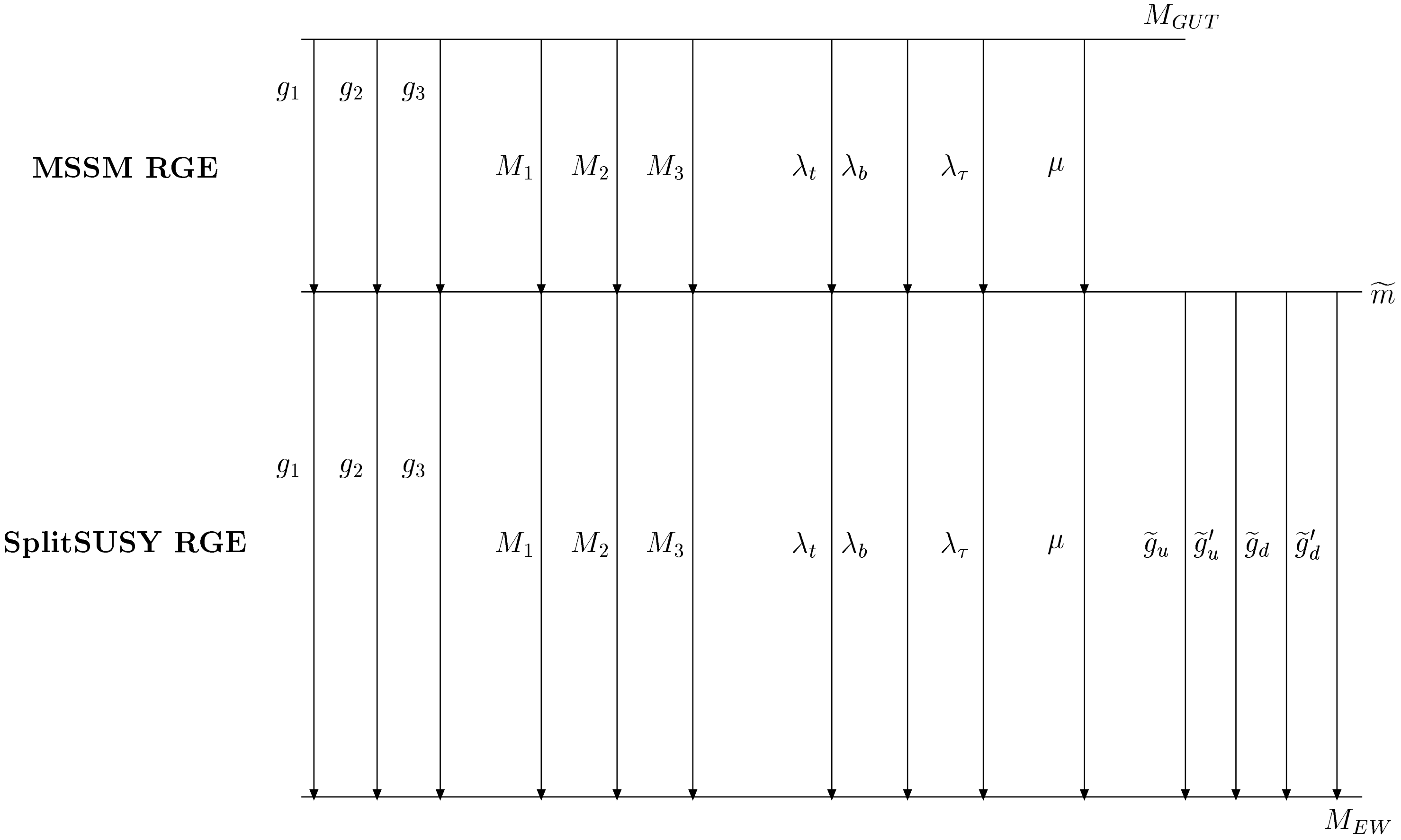
$$\mathcal{L} = m^2 h^\dagger h - \frac{\lambda}{2}\left(h^\dagger h\right)^2 - \Big[h^u_{ij}\bar{q}_j u_i \epsilon h^* + h^d_{ij}\bar{q}_j d_i h + h^e_{ij}\bar{\ell}_j e_i h$$

$$+ \frac{M_3}{2}\tilde{g}^A\tilde{g}^A + \frac{M_2}{2}\tilde{W}^a\tilde{W}^a + \frac{M_1}{2}\tilde{B}\tilde{B} + \mu \tilde{H}_u^T \epsilon \tilde{H}_d$$

$$+ \frac{h^\dagger}{\sqrt{2}}\left(\tilde{g}_u \sigma^a \tilde{W}^a + \tilde{g}'_u \tilde{B}\right)\tilde{H}_u + \frac{h^T \epsilon}{\sqrt{2}}\left(-\tilde{g}_d \sigma^a \tilde{W}^a + \tilde{g}'_d \tilde{B}\right)\tilde{H}_d$$

$$+ \text{h.c.}\Big]$$

Renormalization Group Evolution



M_{GUT}

MSSM RGE

g_1 g_2 g_3 M_1 M_2 M_3 λ_t λ_b λ_τ μ

$\widetilde{m}$

SplitSUSY RGE

g_1 g_2 g_3 M_1 M_2 M_3 λ_t λ_b λ_τ μ $\widetilde{g}_u$ $\widetilde{g}'_u$ $\widetilde{g}_d$ $\widetilde{g}'_d$

M_{EW}

Interaction terms of the SUSY Higgs doublets H_u and H_d

$$\mathcal{L}_{\text{su}} = -\frac{g^2}{8}\left(H_u^\dagger\sigma^a H_u + H_d^\dagger\sigma^a H_d\right)^2 - \frac{g'^2}{8}\left(H_u^\dagger H_u - H_d^\dagger H_d\right)^2$$

$$+\lambda^u_{ij} H_u^T \epsilon \bar{u}_i q_j - \lambda^d_{ij} H_d^T \epsilon \bar{d}_i q_j - \lambda^e_{ij} H_e^T \epsilon \bar{e}_i \ell_j$$

$$-\frac{H_u^\dagger}{\sqrt{2}}\left(g\sigma^a\tilde{W}^a + g'\tilde{B}\right)\tilde{H}_u - \frac{H_d^\dagger}{\sqrt{2}}\left(g\sigma^a\tilde{W}^a - g'\tilde{B}\right)\tilde{H}_d + \text{h.c.}$$

Coupling constants of the effective theory at the scale $\tilde{m}$ are obtained by matching $\mathcal{L}$ and $\mathcal{L}_{\text{su}}$

$$h = -cos\beta\epsilon H_d^* + sin\beta H_u$$

$H_u \to \sin\beta H$, $H_d \to \cos\beta\epsilon H^*$

Matching conditions of various couplings at $\tilde{m}$

$$\lambda(\tilde{m}) = \frac{\left[g^2(\tilde{m}) + g'^2(\tilde{m})\right]}{4} \cos^2 2\beta$$

$$h^u_{ij}(\tilde{m}) = \lambda^{u*}_{ij}(\tilde{m}) \sin\beta, \quad h^{d,e}_{ij}(\tilde{m}) = \lambda^{d,e*}_{ij}(\tilde{m}) \cos\beta,$$

$$\tilde{g}_u(\tilde{m}) = g(\tilde{m}) \sin\beta, \quad \tilde{g}_d(\tilde{m}) = g(\tilde{m}) \cos\beta,$$

$$\tilde{g}'_u(\tilde{m}) = g'(\tilde{m}) \sin\beta, \quad \tilde{g}'_d(\tilde{m}) = g'(\tilde{m}) \cos\beta$$

Couplings of the light Higgs in split effective theory at $\tilde{m}$ are obtained by matching its Lagrangian with the interaction terms of H_u and H_d in the fully supersymmetric theory valid at higher scales

$$h_t(\tilde{m}) = \lambda_t^*(\tilde{m}) \sin\beta$$

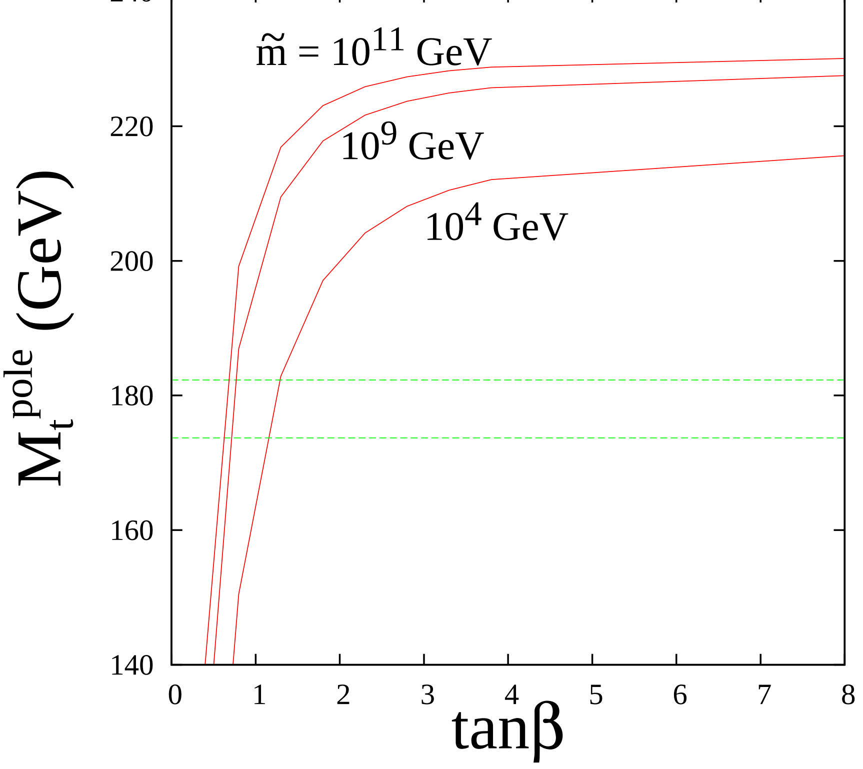
Below the scale $\tilde{m}$, h_t evolves according to split SUSY RGE

Infra-red fixed point $h_t = h_t^f$

Top quark pole mass

$$M_t^{pole} = h_t^f(M_Z) v (1 + \frac{4\alpha_3(M_Z)}{3\pi} - 2Y_t'^f(M_Z))$$

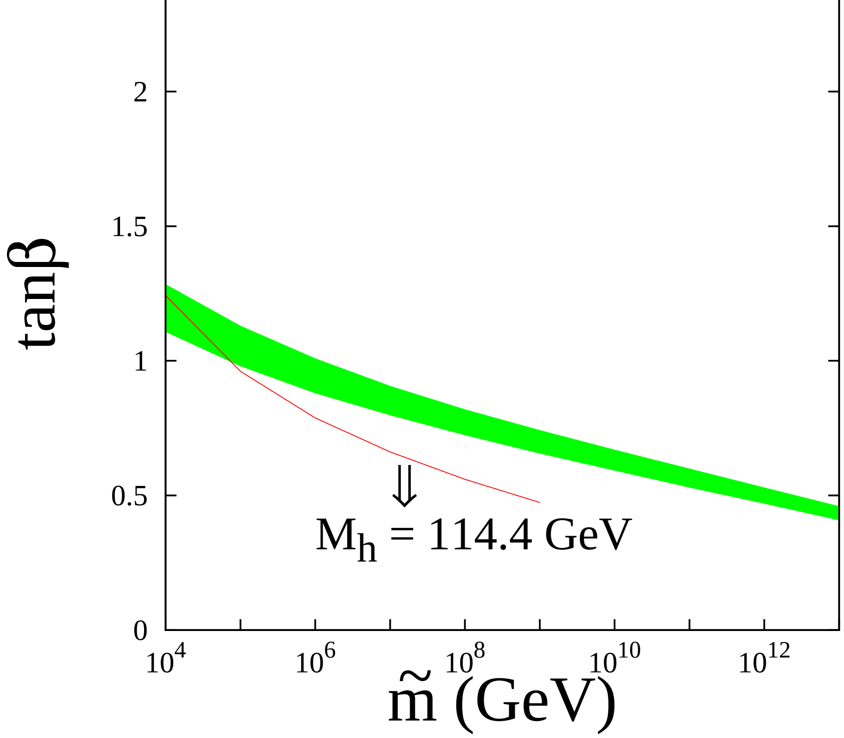
v ≈ 246 GeV and $Y_t'^f = (\frac{h_t^f}{4\pi})^2$



Top quark mass at the infra-red fixed point value of Y_t as a function of $\tan\beta$ for three different values of $\tilde{m}$.

The two horizontal lines are the 1-σ errors on the top quark mass from the Tevatron experiment

$$M_t^{pole} = 178.0 \pm 4.3 \text{ GeV}$$



Allowed region in the $\tilde{m} - \tan\beta$ plane from the experimental limits on top quark mass and the position of the infra-red fixed point value

Value of $\tan\beta$ depends on $|B|$

Gravity, gauge or anomaly mediation: $|B| \sim \tilde{m}$

$\Rightarrow$ $\tan\beta \sim \tilde{m}/m_{EW}$

Difficult to keep $\tan\beta$ in the allowed region

Infrared fixed point scenario is strongly disfavored

Direct mediation mechanism with D-term SUSY breaking

$|B| \gg \tilde{m},\ B\mu \sim \tilde{m}^2$

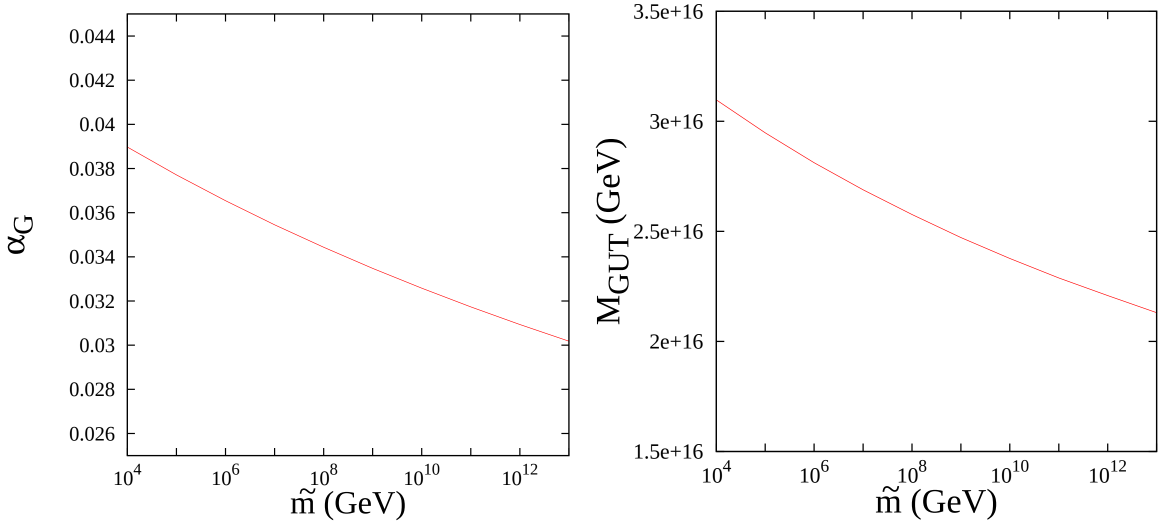
$\tan\beta \sim 1$ is possible with a large splitting in spectrum

In the context of gravity, gauge or anomaly mediation one needs $m^2_{H_d} \ll \tilde{m}^2$

$\Rightarrow$ additional unnatural cancellations

Nevertheless, assume that fixed point scenario is allowed in SpS and look at its implications for other masse and couplings

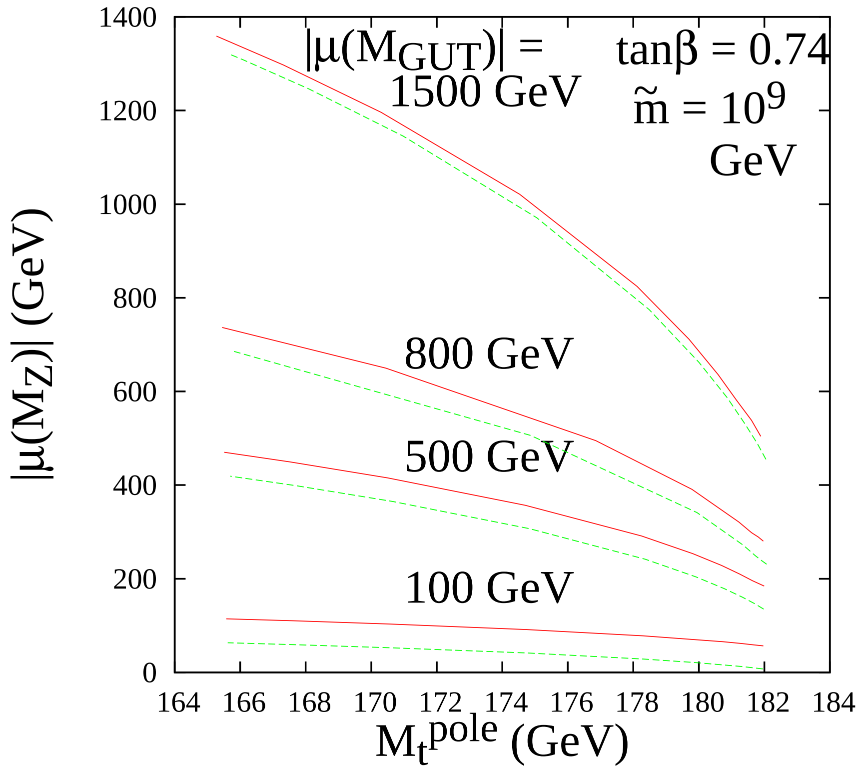
Fixed point behaviour depends also on gauge coupling strengths



Unified coupling strength α_G and grand unifying scale M_{GUT} as functions of $\tilde{m}$.

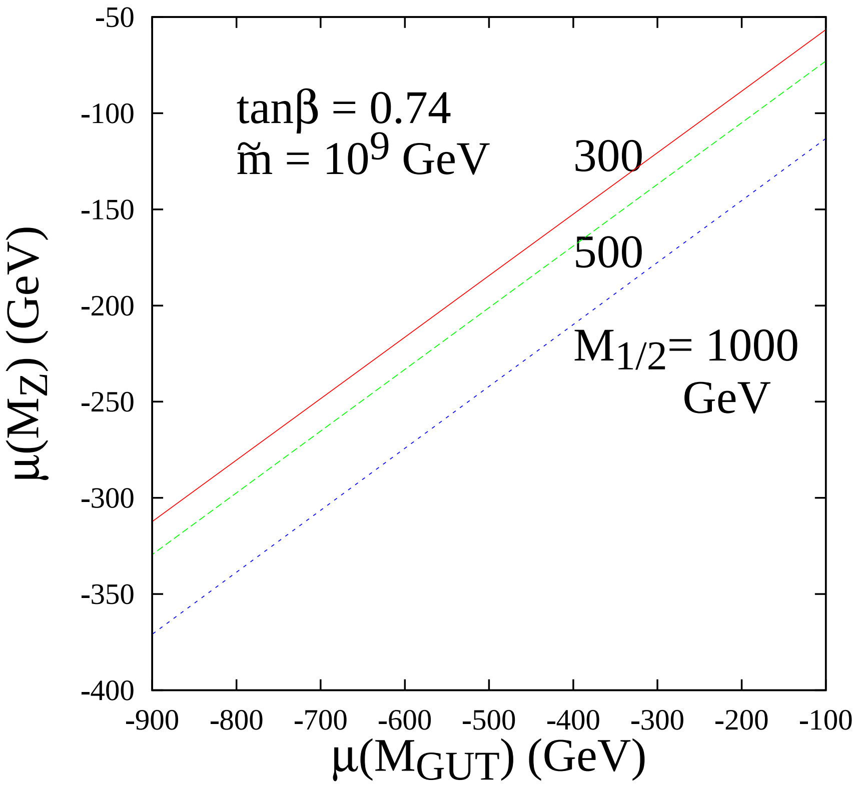
$\alpha_2(M_Z) \approx 0.0335$ $\alpha_1(M_Z) \approx 0.0168$

Higgsino mass parameter $\mu(M_Z)$ changes sharply (for larger values of $\mu(M_{GUT})$) near the fixed point



$\mu(M_Z)$ can be determined (possibly with $\tan\beta$) from the neutralino-chargino system at lepton colliders

Hence, with a precise determination of the top mass one can predict the value of $\mu(M_{GUT})$ for a given $\tilde{m}$



Variation of $\mu(M_Z)$ with the gaugino masses

Inequality of the gauge and gaugino coupling strengths below the scale $\tilde{m}$

$$\mathcal{L}_{gaugino-int.} = \frac{h^{\dagger}}{\sqrt{2}}(\tilde{g}_u \sigma^a \tilde{W}^a + \tilde{g}'_u \tilde{B})\tilde{H}_u$$

$$+\frac{h^T \epsilon}{\sqrt{2}}(-\tilde{g}_d \sigma^a \tilde{W}^a + \tilde{g}'_d \tilde{B})\tilde{H}_d + h.c.$$

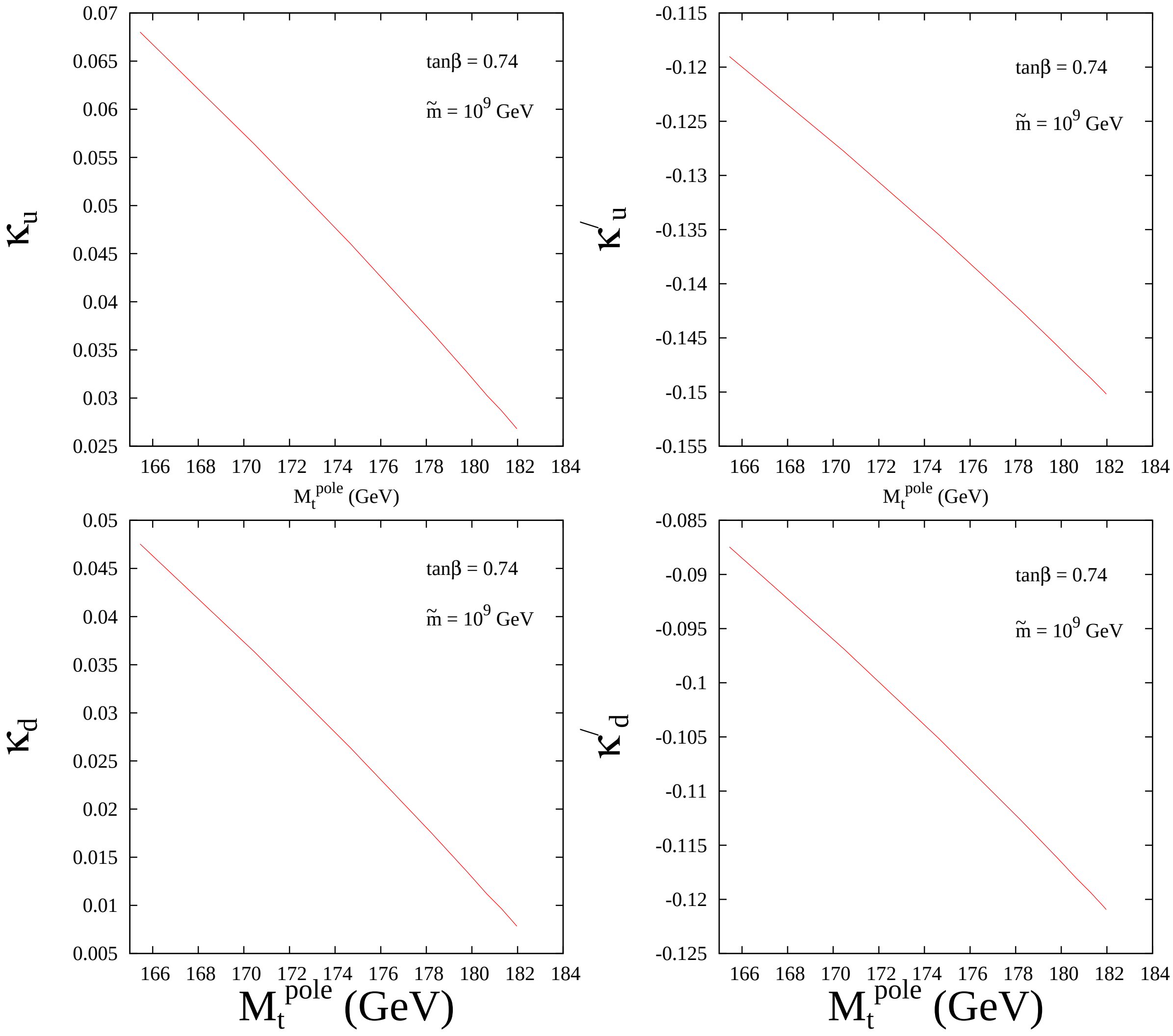
$$\tilde{g}_u(\tilde{m}) = g(\tilde{m})\ \mathrm{sin}\beta,\ \ \tilde{g}_d(\tilde{m}) = g(\tilde{m})\ \mathrm{cos}\beta$$

$$\tilde{g}'_u(\tilde{m}) = g'(\tilde{m})\ \mathrm{sin}\beta,\ \ \tilde{g}'_d(\tilde{m}) = g'(\tilde{m})\ \mathrm{cos}\beta$$

Define ‘anomalous’ gaugino couplings

$$\kappa_u = 1 - \frac{\tilde{g}_u}{g\ \mathrm{sin}\beta},\ \ \kappa_d = 1 - \frac{\tilde{g}_d}{g\ \mathrm{cos}\beta}$$

$$\kappa'_u = 1 - \frac{\tilde{g}'_u}{g'\ \mathrm{sin}\beta},\ \ \kappa'_d = 1 - \frac{\tilde{g}'_d}{g'\ \mathrm{cos}\beta}$$



Measurements of gaugino couplings $\tilde{g}$ and gauge couplings g lead to the determination of $\tilde{m}$: the couplings $\kappa_{u,d}$ and $\kappa'_{u,d}$ vanish at the scale $\tilde{m}$

Conclusions

•Infra-red fixed point behaviour of Y_t and its associated phenomenology has been studied in split-supersymmetry.

•In the fixed point scenario we find a thin band is allowed in $\tan\beta - \tilde{m}$ plane.

•Even if one does not assume the exaxt fixed point value for the top mass, there is still a lower limit on the parameter $\tan\beta$ (< 1) as a function of $\tilde{m}$.

•Interesting behaviour of $\mu(M_Z)$ near the fixed point.

• $\mu(M_{GUT})$ can be predicted from a precise measurement of m_t and $\mu(M_Z)$.

Very recently, Delgado and Giudice (hep-ph/0506217) have shown that with SU(5) GUT boundary conditions for the soft masses and from the conditions of no charge or color breaking minima (A. Ibarra, hep-ph/0503160) one can conclude that it is not possible to have the top Yukawa coupling at the infrared fixed point