Shifted Focus Point from Minimal Mixed Mediation of SUSY Breaking
: focus point scenario revisited

Bumseok KYAE
(Pusan Nat'l Univ.)

1. **arXiv: 1502.02311**

2. arXiv: 1403.6527 [PRD 90(2014)035023]
collaborated with Chang Sub Shin (Rutgers U.)

Feb. 15 (2015)
@ HPNP2015 (U. of Toyama)

- The naturalness problem of EW scale and Higgs boson mass has been the most important issue for last four decades.
- The MSSM has been the most promising BSM candidate.
- No evidence of BSM has been observed yet at LHC.

→ Theoretical puzzles raised in the SM still remain unsolved.

- A barometer of the solution to the naturalness problem is the stop mass .

  The stop mass bound has been already > 700 GeV.

  The gluino mass bound has exceeded > 1.4 TeV.

→ They start threatening the traditional status of SUSY as a solution to the naturalness problem of the EW phase transition.

- ATLAS and CMS have discovered
  the SM(-like) Higgs with 125-126 GeV mass.

- According to the recent analysis based on 3-loop calculation,
  3-4 TeV stop mass is necessary for the 126 GeV Higgs mass
  (without a large stop mixing). [Feng, etal. PRL (2013)]

- ATLAS and CMS have discovered the SM(-like) Higgs with 125-126 GeV mass.
- According to the recent analysis based on 3-loop calculation, 3-4 TeV stop mass is necessary for the 126 GeV Higgs mass (without a large stop mixing). [Feng, etal. PRL (2013)]

A fine-tuning of 10^{-3} – 10^{-4}

seems to be unavoidable !! ??

Can m_{hu}^2 be insensitive to the stop mass ??

We need such a model for naturalness of the EW scale.

Focus Point scenario

[Feng, Matchev, Moroi (2000)]

Suppose that

1. Universal soft mass : $m_{q3}^2 = m_{u3}^2 = m_{hu}^2 = \; ... \; = m_0^2$

   at the GUT scale

2. Small enough gaugino mass : $m_{1/2}^2 << m_0^2$, and $A_0 << m_0$

Then, the Higgs mass parameter m_{hu}^2 becomes insensitive to m_0^2 or stop mass squared.

Focus Point scenario

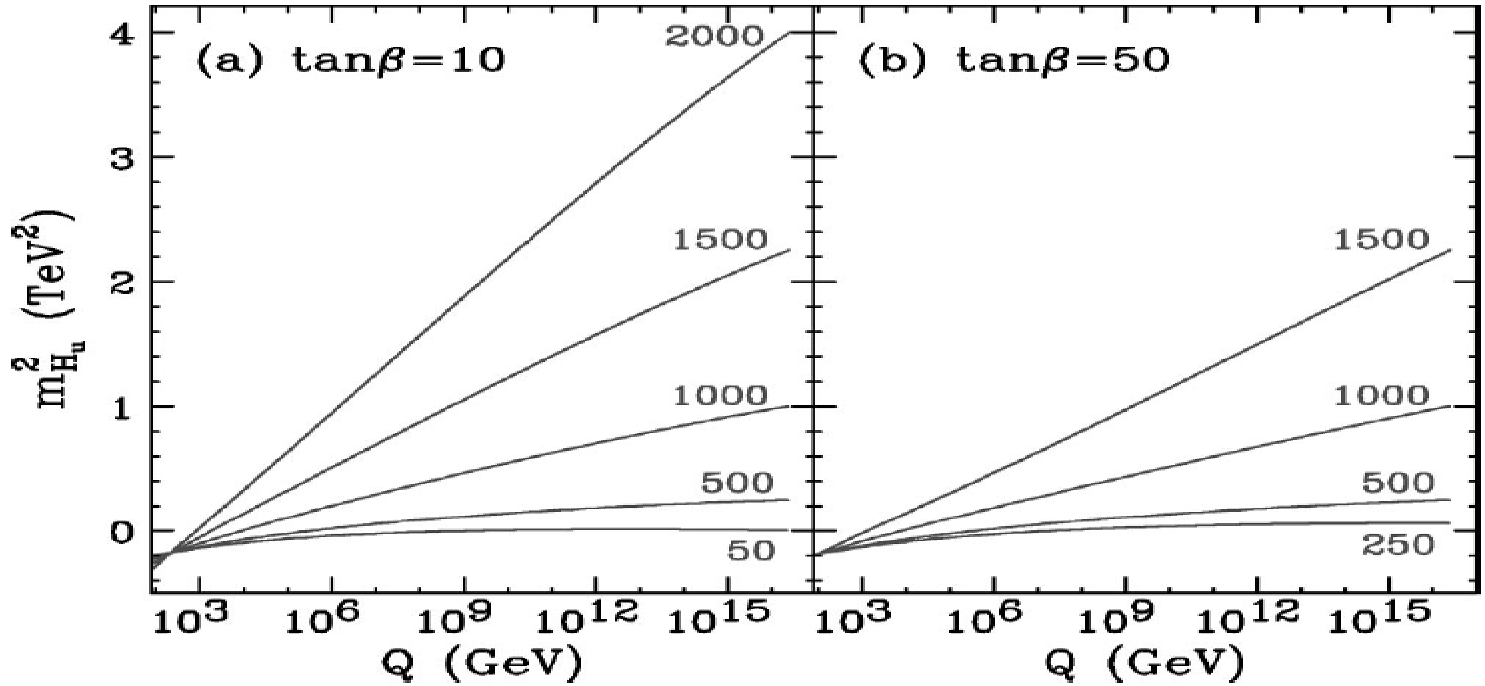
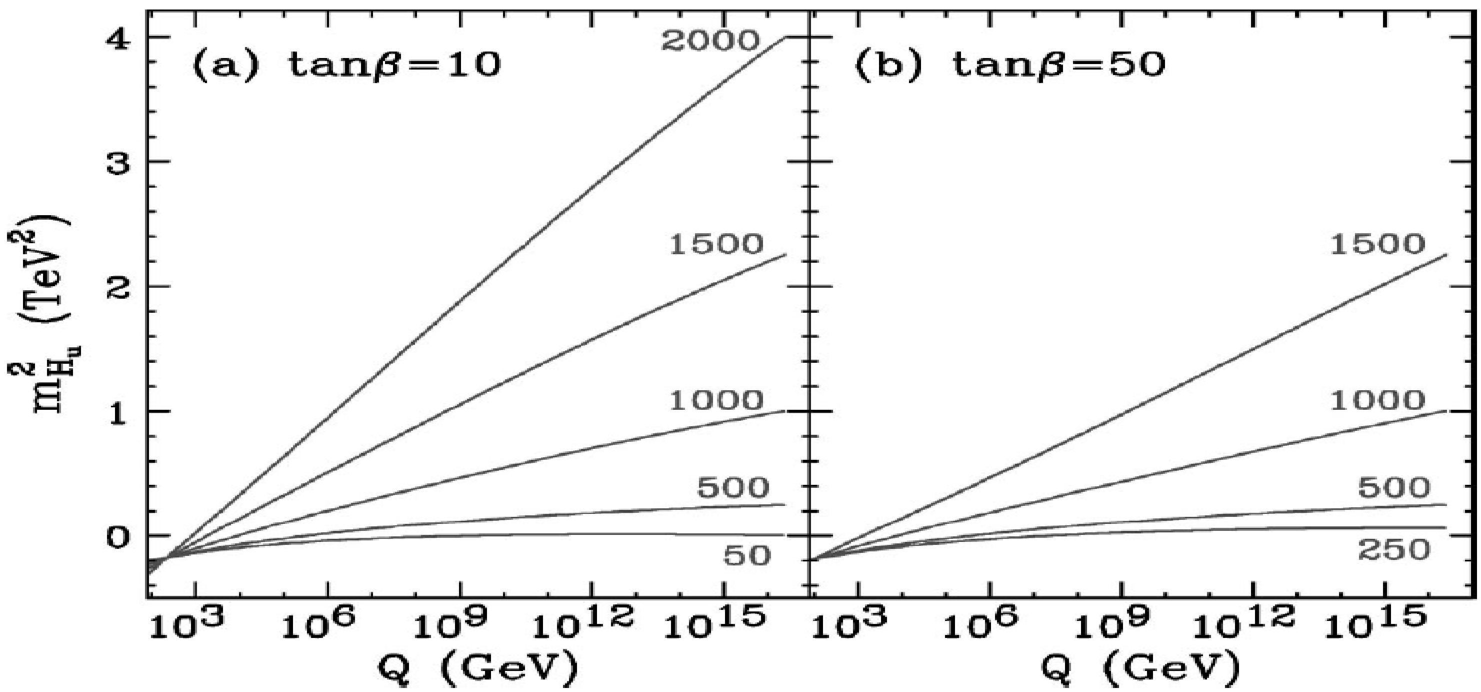


FIG. 1. The RG evolution of $m^2_{H_u}$ for (a) $\tan\beta = 10$ and (b) $\tan\beta = 50$, several values of m_0 (shown, in GeV), $M_{1/2} = 300$ GeV, $A_0 = 0$, and $m_t = 174$ GeV. For both values of $\tan\beta$, $m^2_{H_u}$ exhibits an RG focus point near the weak scale, where $Q_F^{(H_u)} \sim \mathcal{O}(100\text{ GeV})$, irrespective of m_0.

[Feng, Matchev, Moroi, PRL, PRD (2000)]

Focus Point scenario



Then, the Higgs mass parameter m_{hu}^2 becomes insensitive to m_0^2 or stop mass squared.

Challenges

from experiments

1. The gluino mass bound has already exceeded
   $M_3 > 1.4$ TeV.
   $M_{1/2}$ should NOT be small any longer.
   $$\rightarrow \quad m_{hu}^2 < -(1\ \mathrm{TeV})^2$$

2. The stop mass bound has exceeded 700 GeV.
   If stop masses > 1 TeV, then ???

Challenges

from theory

1. 3-4 TeV stop masses are necessary for 126 GeV Higgs mass without A_t at 3-loop level.

[Feng, etal., PRL (2013)]

The needed 3-4 TeV stop decoupling scale is too high from the FP scale.

2. How to get the almost vanishing A-term?

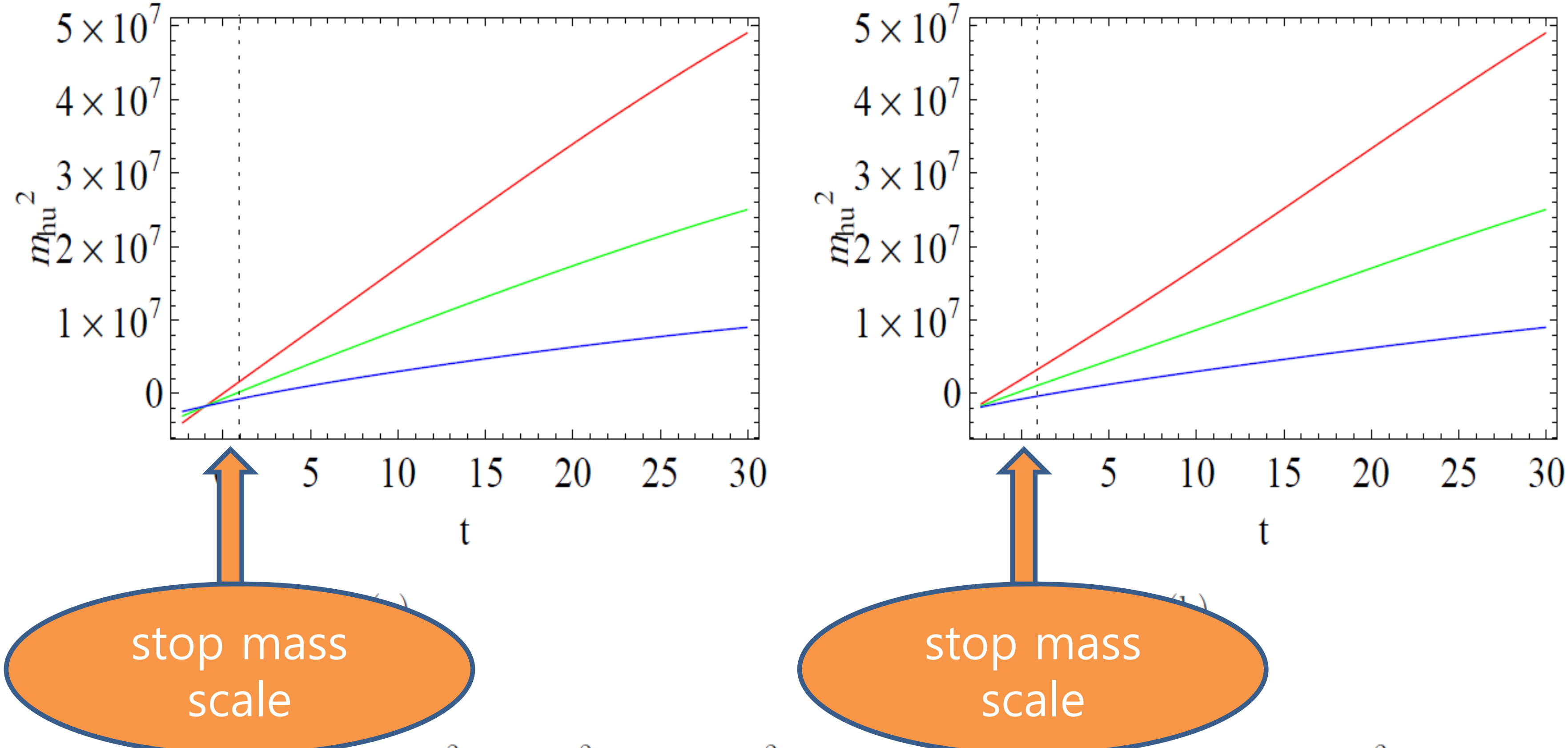
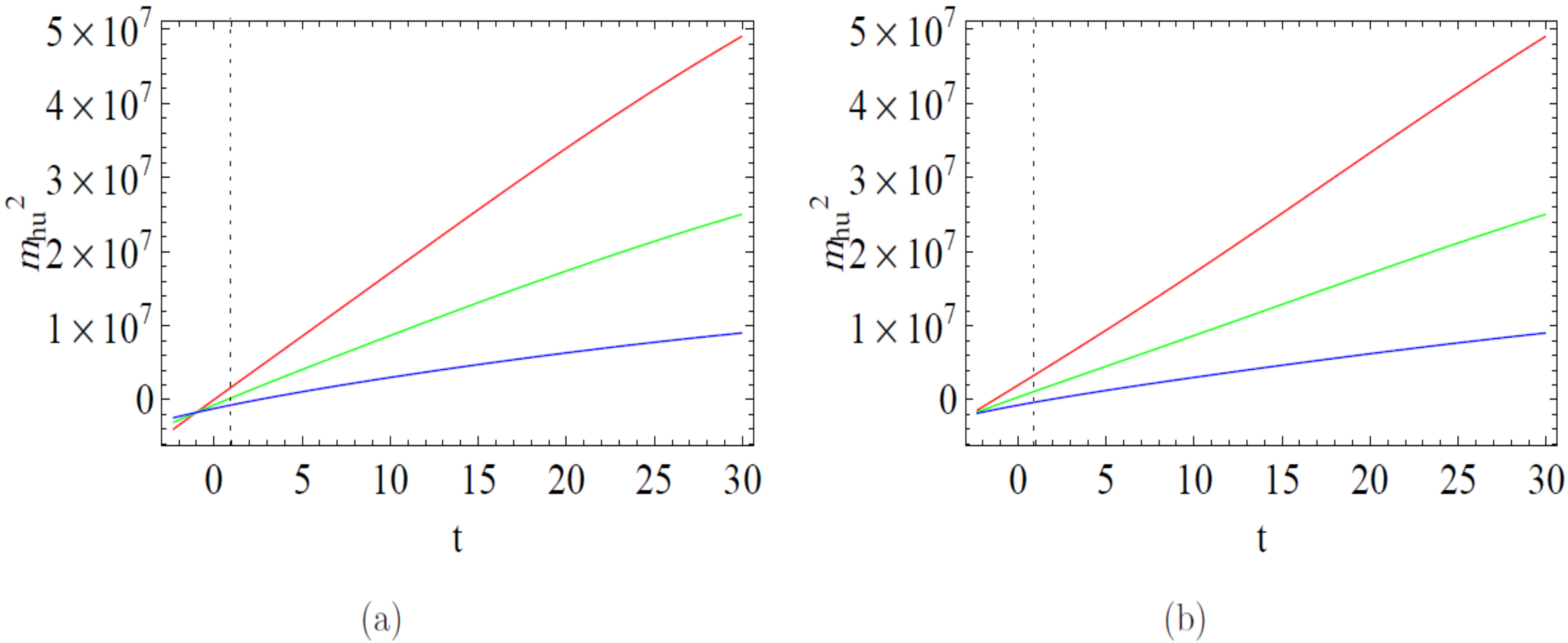


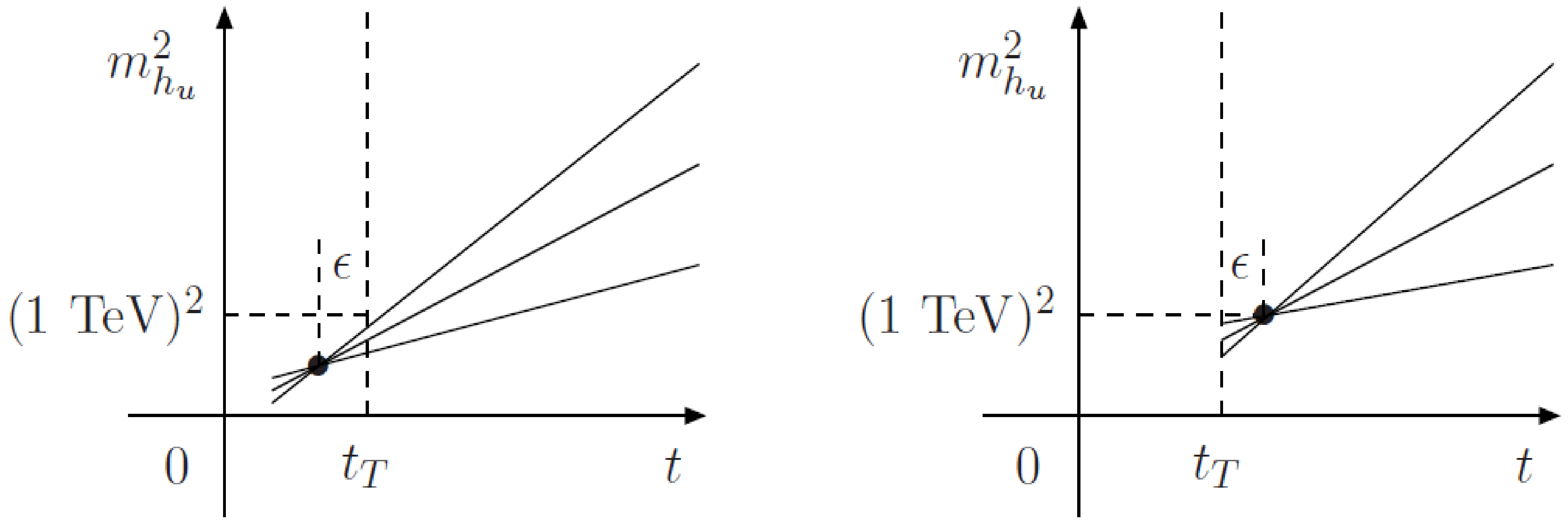
FIG. 1: RG evolutions of $m_{h_u}^2$ for $m_0^2 = (7\,\text{TeV})^2$ [Red], $(5\,\text{TeV})^2$ [Green], and $(3\,\text{TeV})^2$ [Blue], and for **(a)** $\tan\beta = 5$ and **(b)** $\tan\beta = 50$, when $m_{1/2} = 1\,\text{TeV}$ and $A_0 = 0$. Here we take $\alpha_G = 1/25$. The unit of the vertical axis is $(\text{GeV})^2$. The dotted lines at $t \approx 0.92$ denote the assumed stop decoupling scale, $Q = 5\,\text{TeV}$. $t \approx -2.3$ [$t \approx 29.9$] corresponds to $Q = 200\,\text{GeV}$ [$Q = 2\times10^{16}\,\text{GeV}$]. Below the stop decoupling scale, the above RG runnings must be modified. The above figures show that the extrapolated FP, where $m_{h_u}^2$ is negative, appears at a relatively higher (lower) energy scale for small (large) $\tan\beta$.



$$\Delta_{m_0^2} = \left| \frac{\partial \log m_Z^2}{\partial \log m_0^2} \right| = \left| \frac{m_0^2}{m_Z^2} \frac{\partial m_Z^2}{\partial m_0^2} \right| \quad \sim \mathbf{1000}$$

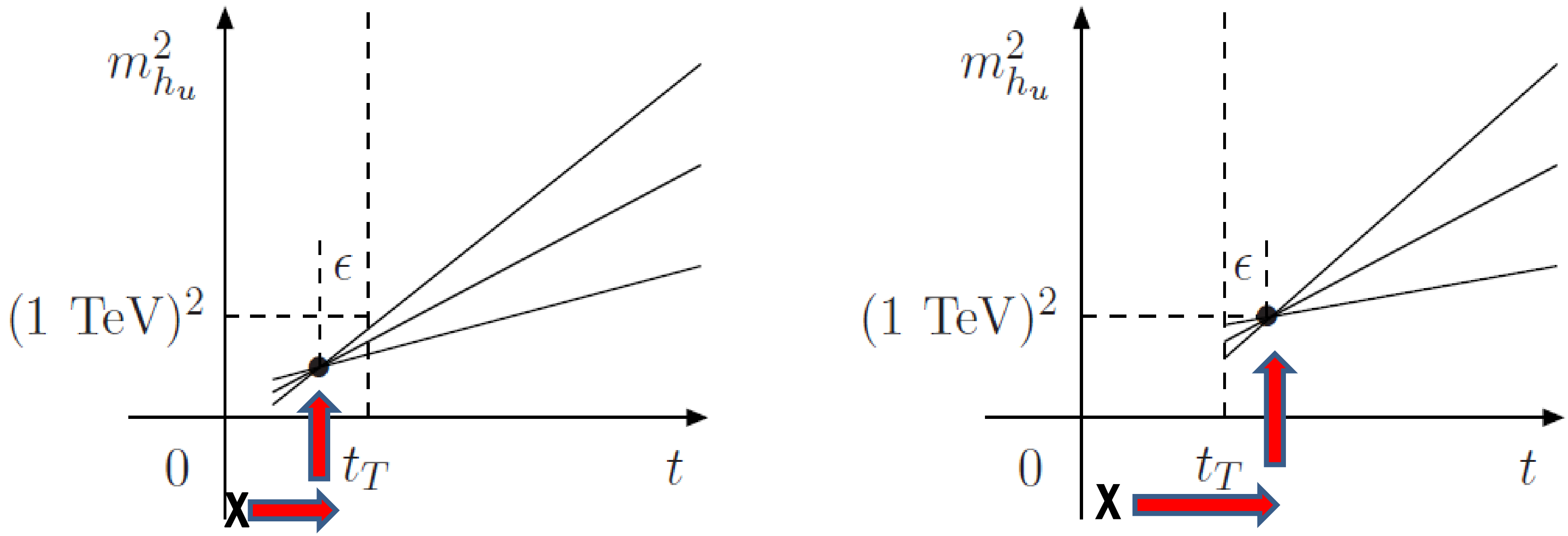
FIG. 1: I[...]ue], and for **(a)** t[...] $= 1/25$. The unit[...]ed stop decoupling scale, $Q = 5$ TeV. $t \approx -2.3$ $[t \approx 29.9]$ corresponds to $Q = 200$ GeV $[Q = 2 \times 10^{\ldots 6}$ GeV]. Below the stop decoupling scale, the above RG runnings must be modified. The above figures show that the extrapolated FP, where $m_{h_u}^2$ is negative, appears at a relatively higher (lower) energy scale for small (large) $\tan\beta$.

For predictively small EW scale



FP needs to appear around stop mass scale (3-4 TeV), and $|m_{hu}^2| < (1\ \mathrm{TeV})^2$ there.

For predictively small EW scale



FP needs to appear around stop mass scale (3-4 TeV), and $|m_{h_u}^2| < (1\ \mathrm{TeV})^2$ there.

Below the stop mass scale

$$m_{h_u}^2(t_W) \approx m_{h_u}^2|_{\Lambda_T} + \frac{3|y_t|^2}{8\pi^2}\left[(\widetilde{m}_t^2 + m_t^2)\left\{\log\frac{\widetilde{m}_t^2 + m_t^2}{\Lambda_T^2} - 1\right\} - m_t^2\left\{\log\frac{m_t^2}{\Lambda_T^2} - 1\right\}\right]$$

$$\approx m_{h_u}^2|_{\Lambda_T} - \frac{3|y_t|^2}{8\pi^2}\widetilde{m}_t^2,$$

m_{hu}^2 further decreases by $\sim(550\ \text{GeV})^2$ from Q = 3-4 TeV to $Q = M_Z$.

How can we shift the Focus Point of m_{hu}^2 upto the desired stop mass scale (3-4 TeV) ??

How can we shift the Focus Point of m_{hu}^2 upto the desired stop mass scale (3-4 TeV) ??

minimal Gravity mediation

+

minimal Gauge mediation

Minimal Gravity Mediation

With the minimal Kahler pot., and superpot.
where the Hidden and Observ. Sectors are separated,

$$K = \sum_{i,a} |z_i|^2 + |\phi_a|^2 \ , \qquad W = W_H(z_i) + W_O(\phi_a)$$

$$\langle z_i \rangle = b_i M_P, \ \langle \partial_{z_i} W_H \rangle = a_i^* m M_P, \ \underline{\langle W_H \rangle = m M_P^2},$$

Minimal Gravity Mediation

With the minimal Kahler pot., and superpot.
where the Hidden and Observ. Sectors are separated,

$$K = \sum_{i,a} |z_i|^2 + |\phi \ldots \qquad W = W_H(z_i) + W_O(\phi_a)$$

$$F_{z_i} = \frac{\partial W_H}{\partial z_i} + z_i^* \frac{W}{M_P^2} = M_P \left[(a_i^* + b_i^*)\, m + b_i^* \frac{W_O}{M_P^2} \right]$$

$$F_{\phi_a} = \frac{\partial W_O}{\partial \phi_a} + \phi_a^* \frac{W}{M_P^2} = \frac{\partial W_O}{\partial \phi_a} + \phi_a^* \left(m + \frac{W_O}{M_P^2} \right).$$

Minimal Gravity Mediation

With the minimal Kahler pot., and superpot.
where the Hidden and Observ. Sectors are separated,

$$K = \sum_{i,a} |z_i|^2 + |\phi_a|^2 \ , \qquad W = W_H(z_i) + W_O(\phi_a)$$

$$\langle z_i \rangle = b_i M_P, \ \langle \partial_{z_i} W_H \rangle = a_i^* m M_P, \ \underline{\langle W_H \rangle = m M_P^2},$$

$$V_F = e^{\frac{K}{M_P^2}} \left[|F_{z_i}|^2 + |F_{\phi_a}|^2 - \frac{3}{M_P^2} |W|^2 \right]$$

Minimal Gravity Mediation

With the minimal Kahler pot., and superpot.

where the Hidden and Observ. Sectors are separated,

For the *vanishing* Cosmological Constant,

$$\sum_i \langle |F_{z_i}|^2 \rangle = 3|\langle W_H \rangle|^2/M_P^2, \text{ or } \sum_i |a_i + b_i|^2 = 3$$

$$W_H(z_i) + W_O(\phi_a)$$

$$\langle z_i \rangle \quad a_i^* m M_P, \ \langle W_H \rangle = m M_P^2,$$

$$V_F = e^{\frac{K}{M_P^2}} \left[|F_{z_i}|^2 + |F_{\phi_a}|^2 - \frac{3}{M_P^2}|W|^2 \right]$$

Minimal Gravity Mediation

With the minimal Kahler pot., and superpot.
where the Hidden and Observ. Sectors are separated,

$$K = \sum_{i,a} |z_i|^2 + |\phi_a|^2 \ , \qquad W = W_H(z_i) + W_O(\phi_a)$$

$$\langle z_i \rangle = b_i M_P, \ \langle \partial_{z_i} W_H \rangle = a_i^* m M_P, \ \underline{\langle W_H \rangle = m M_P^2},$$

$$\boxed{\begin{aligned} V_F \approx \left| \partial_{\phi_a} \widetilde{W}_O \right|^2 + \underline{m_0^2} |\phi_a|^2 \\ + \underline{m_0} \left[\phi_a \partial_{\phi_a} \widetilde{W}_O + (A_\Sigma - 3) \widetilde{W}_O + \text{h.c.} \right] \end{aligned}}$$

Minimal Gravity Mediation

With the minimal Kahler pot., and superpot.

where the Hidden and Observ. Sectors are separated,

Universal Soft Masses:

$$m_{h_u}^2 = m_{h_d}^2 = m_{q_3}^2 = m_{u_3^c}^2 = \cdots = m_0^2$$

A-terms $\propto m_0$

$$\ldots W_H(z_i) + W_O(\phi_a)$$

$$\langle z_i \rangle \ldots = a_i m M_P, \ \langle W_H \rangle = m M_P^2,$$

$$V_F \approx \left| \partial_{\phi_a} \widetilde{W}_O \right|^2 + m_0^2 |\phi_a|^2$$
$$+ m_0 \left[\phi_a \partial_{\phi_a} \widetilde{W}_O + (A_\Sigma - 3) \widetilde{W}_O + \text{h.c.} \right]$$

Minimal Gravity Mediation

With the minimal Kahler pot., and superpot.
where the Hidden and Observ. Sectors are separated,

Universal Soft Masses:

$$m_{h_u}^2 = m_{h_d}^2 = m_{q_3}^2 = m_{u_3^c}^2 = \cdots = m_0^2$$

A-terms ∝ m_0

$\langle z_i \rangle$ … $= a_i^{\prime} m M_P,$

Assume
f_{ab} = const.
So **$M_a = 0$**
at tree level.

$$V_F \approx \left|\partial_{\phi_a} \widetilde{W}_O\right|^2 + m_0^2 |\phi_a|^2 + m_0 \left[\phi_a \partial_{\phi_a} \widetilde{W}_O + (A_\Sigma - 3)\widetilde{W}_O + \text{h.c.}\right]$$

Minimal Gauge Mediation

With ONE pair of messenger fields $\{\mathbf{5}, \mathbf{5^*}\}$,

$$W_m = y_S S\, 5\, 5^*$$

$$M_a = \frac{g_a^2}{16\pi^2}\frac{\langle F_S\rangle}{\langle S\rangle}, \ m_i^2 = 2\sum_{a=1}^{3}\left[\frac{g_a^2}{16\pi^2}\frac{\langle F_S\rangle}{\langle S\rangle}\right]^2 C_a(i)$$

where $C_a(i)$ is the quadratic Casimir invariant $(T^a T^a)_i^j = C_a(i)\delta_i^j$

Minimal **Gauge** Mediation

With ONE pair of messenger fields {***5***, ***5****} ,

Non-universal

(dep. on flavors)

Soft Mass corrections !!

$$M_a = \frac{g_a^2}{16\pi^2}\frac{\langle F_S\rangle}{\langle S\rangle}, \;\; m_i^2 = 2\sum_{a=1}^{3}\left[\frac{g_a^2}{16\pi^2}\frac{\langle F_S\rangle}{\langle S\rangle}\right]^2 C_a(i)$$

where $C_a(i)$ is the quadratic Casimir invariant $(T^a T^a)_i^j = C_a(i)\delta_i^j$

Minimal Gauge Mediation

With ONE pair of messenger fields {*5*, *5**} ,

$$\langle F_S \rangle = m_0 M_P$$

$$\langle S \rangle = \langle \mathbf{24}_H \rangle$$

$$M_a = \frac{g_a^2}{16\pi^2}\frac{\langle F_S \rangle}{\langle S \rangle}, \quad m_i^2 = 2\sum_{a=1}^{3}\left[\frac{g_a^2}{16\pi^2}\frac{\langle F_S \rangle}{\langle S \rangle}\right]^2 C_a(i)$$

where $C_a(i)$ is the quadratic Casimir invariant $(T^a T^a)_i^j = C_a(i)\delta_i^j$

Minimal Gauge Mediation

With ONE pair of messenger fields {***5***, ***5****} ,

$$\langle F_S \rangle = m_0 M_P$$

$$\langle S \rangle = \langle \mathbf{24}_H \rangle$$

$$M_a = \frac{g_a^2}{1\ldots} \frac{\langle F_S \rangle}{\ldots} \quad \ldots^3 \left[\ldots g^2 \ldots \frac{\langle F_S \rangle}{\ldots} \right]^2 C_a(i) \ldots$$

$$K \supset f(z) S + \text{h.c.}$$

$$\langle W_H \rangle = m M_P^2$$

$$\langle F_S \rangle \approx m \left[f(z) + \langle S^* \rangle \right]$$

where $C_a(i)$ is the qu… $(T^a T^a)_i^j = C_a(i) \delta_i^j$

Minimal **Gauge** Mediation

With **ONE pair** of messenger fields {***5***, ***5****},

$$\langle F_S\rangle = m_0 M_P$$

$$\langle S\rangle = \langle \mathbf{24}_H\rangle$$

ONE SUSY breaking source

but

TWO mediations

$$K \supset f(z)S + \mathrm{h.c.}$$

$$\langle F_S\rangle \approx m\left[f(z) + \langle S^*\rangle\right]$$

$$\langle W_H\rangle = m M_P^2$$

where $C_a(i)$ is the qu… $(T^aT^a)_i^j = C_a(i)\delta_i^j$

Minimal Gauge Mediation

With ONE pair of messenger fields {***5***, ***5****} ,

$$\langle F_S \rangle = m_0 M_P$$

$$\langle S \rangle = \langle \mathbf{24}_H \rangle$$

$$M_a = \frac{g_a^2}{1\ldots} \langle F_\ldots \rangle \ldots {}^3 \left[\ldots {}^2 \ldots \langle F_S \rangle \right]^2 C_a(i)$$

$$K \supset f(z) S + \text{h.c.}$$

$$\langle F_S \rangle \approx m \left[f(z) + \langle S^* \rangle \right] \rightarrow \mathcal{O}(m M_P)$$

where $C_a(i)$ is the qu… …nt $(T^a T^a)_i^j = C_a(i) \delta_i^j$

Minimal Gauge Mediation

With ONE pair of messenger fields {*5*, *5**} ,

$$\langle F_S \rangle = m_0 M_P$$

$$\langle S \rangle = \langle \mathbf{24}_H \rangle$$

Assoc. w/ C.C. prob.

Possible by a GUT Model

$$M_a = \frac{g_a^2}{1\ldots} \langle F \ldots \quad \ldots \sum^{3} \left[\ldots g^2 \ldots \frac{\langle F_S \rangle}{\ldots} \right] C_a(i)$$

$$K \supset f(z) S + \text{h.c.}$$

$$\langle F_S \rangle \approx m \left[f(z) + \langle S^* \rangle \right]$$

where $C_a(i)$ is the qu… …t $(T^a T^a)_i^j = C_a(i)\delta_i^j$

Minimal **Gauge** Mediation

With **ONE pair** of messenger fields $\{\mathbf{5}, \mathbf{5}^*\}$,

$$\langle F_S \rangle = m_0 M_P$$

$$\langle S \rangle = \langle \mathbf{24}_H \rangle$$

$$M_a = \frac{g_a^2}{1\ldots} \langle F_S \rangle \ldots \left[\ldots g^2 \ldots \frac{\langle F_S \rangle}{\ldots} \right]^2 C_a(i)$$

$$\frac{\langle F_S \rangle}{16\pi^2 \langle S \rangle} = \frac{m_0 M_P}{16\pi^2 M_X} \sqrt{\frac{5}{24}} g_G \approx 0.57 \times m_0$$

where $C_a(i)$ is the qu… $(T^a T^a)_i^j = C_a(i)\delta_i^j$

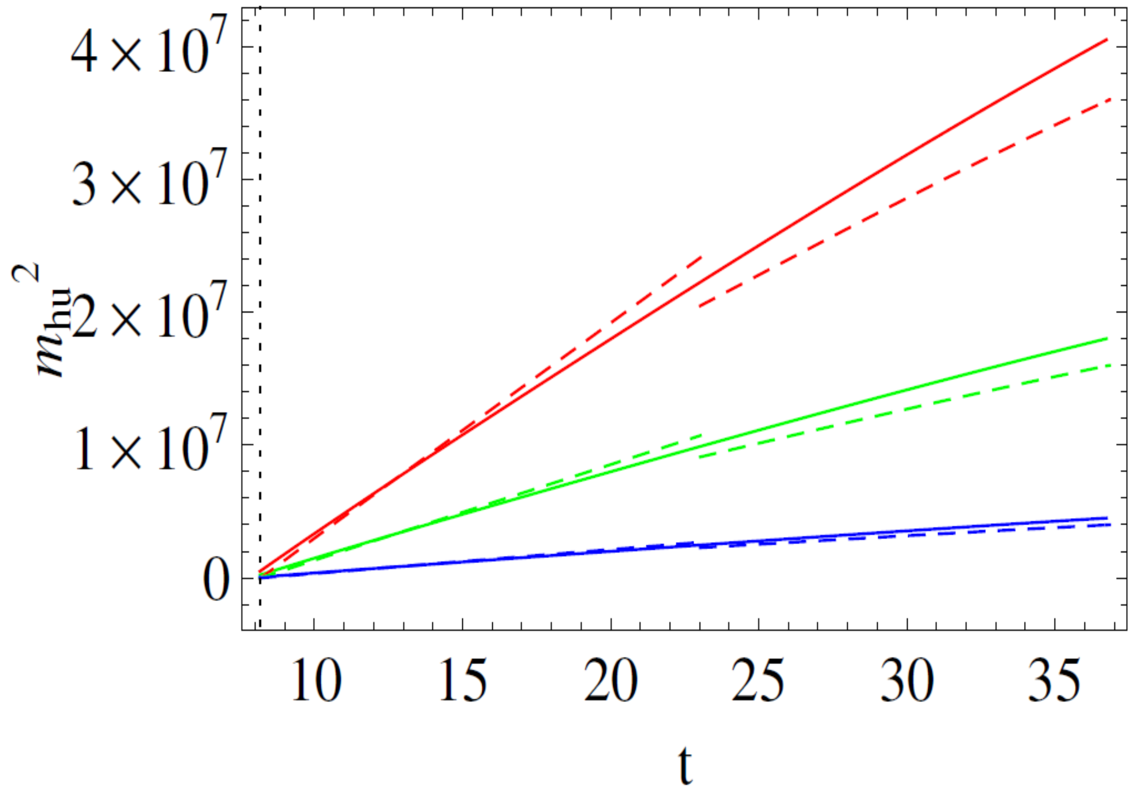


FIG. 1. RG evolutions of $m^2_{h_u}$ with t [$\equiv \log(Q/\,\mathrm{GeV})$] for $m_0^2 = (6\,\mathrm{TeV})^2$ [Red], $(4\,\mathrm{TeV})^2$ [Green], and $(2\,\mathrm{TeV})^2$ [Blue] when $A_t = -0.5\ m_0$ and $\tan\beta = 50$. The tilted straight [dotted] lines correspond to the case of $t_M \approx 36.7$ (or $Q_M = 9\times10^{15}$ GeV, "Case A") [$t_M \approx 23.0$ (or $Q_M = 1\times10^{10}$ GeV, "Case B")]. The vertical dotted line at $t = t_T \approx 8.2$ ($Q_T = 3.5\,\mathrm{TeV}$) indicates the desired stop decoupling scale.

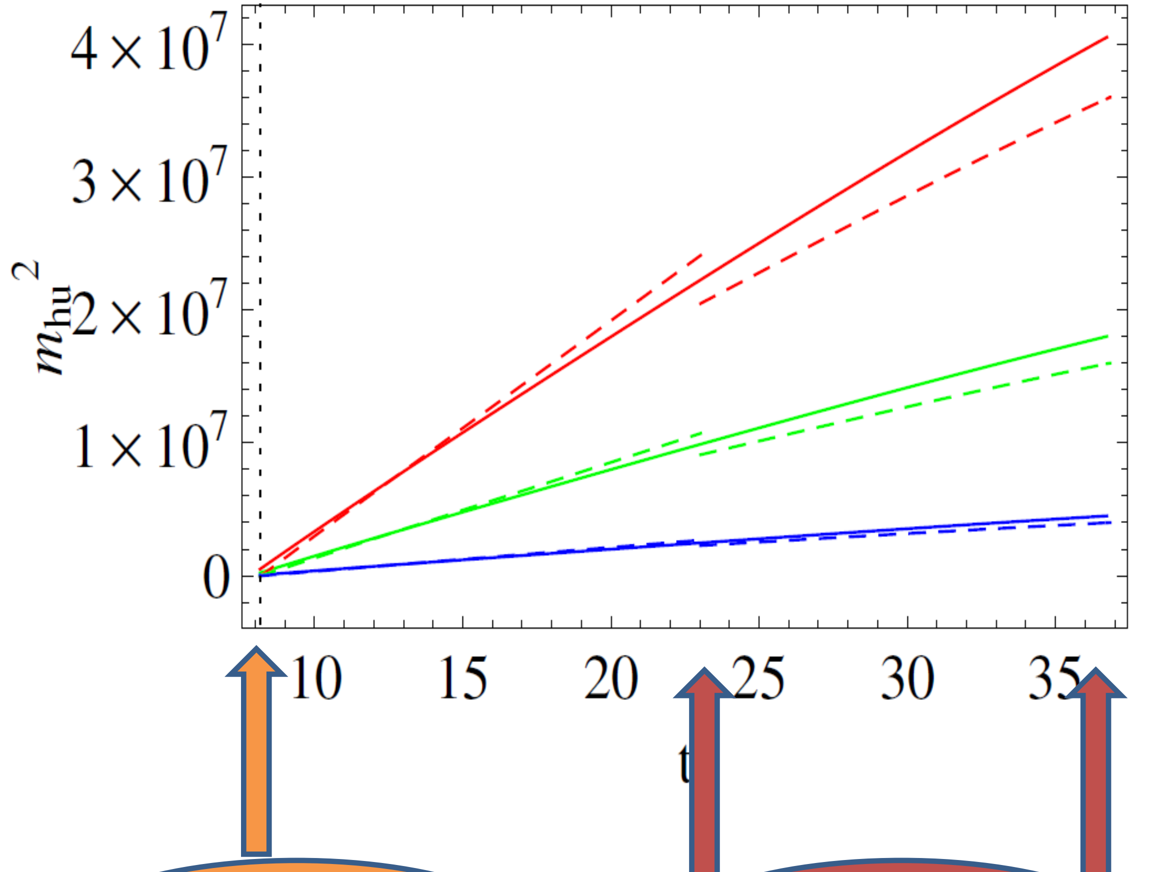


FIG. [illegible] $m^2_{h_u}$ w[illegible]or $m_0^2 = (6$ [illegible] TeV$)^2$ [Green], [illegible] [Blue] when $A_t = -0.5\ m_0$ and $\tan\beta = 50$. The tilted straight [dotted] lines correspond to the case of $t_M \approx 36.7$ (or $Q_M = 9 \times 10^{15}$ GeV, "Case A") [$t_M \approx 23.0$ (or $Q_M = 1 \times 10^{10}$ GeV, "Case B")]. The vertical dotted line at $t = t_T \approx 8.2$ ($Q_T = 3.5$ TeV) indicates the desired stop decoupling scale.

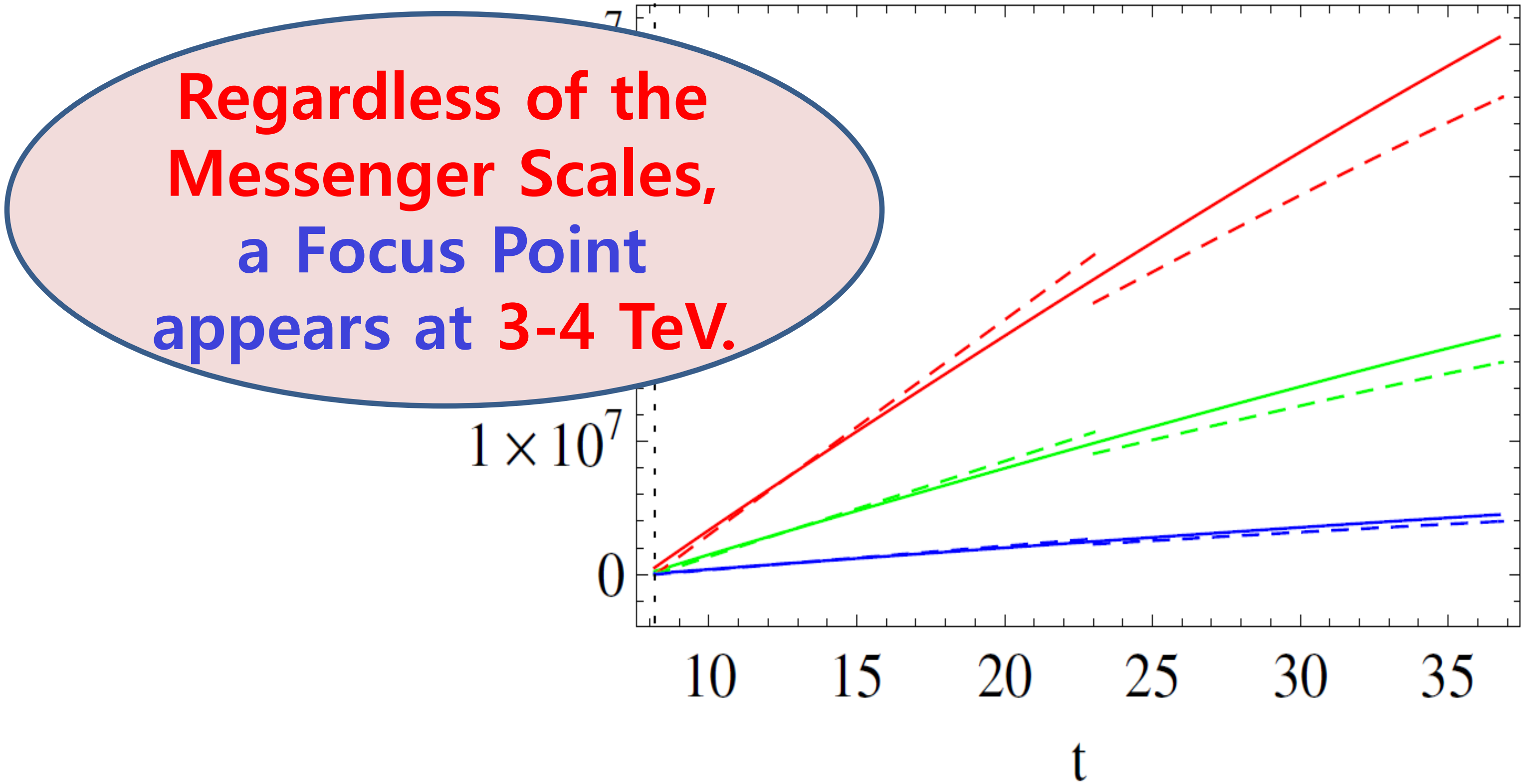


FIG. 1. RG evolutions of $m_{h_u}^2$ with t [$\equiv \log(Q/\,\mathrm{GeV})$] for $m_0^2 = (6\,\mathrm{TeV})^2$ [Red], $(4\,\mathrm{TeV})^2$ [Green], and $(2\,\mathrm{TeV})^2$ [Blue] when $A_t = -0.5\ m_0$ and $\tan\beta = 50$. The tilted straight [dotted] lines correspond to the case of $t_M \approx 36.7$ (or $Q_M = 9\times10^{15}$ GeV, "Case A") [$t_M \approx 23.0$ (or $Q_M = 1\times10^{10}$ GeV, "Case B")]. The vertical dotted line at $t = t_T \approx 8.2$ ($Q_T = 3.5$ TeV) indicates the desired stop decoupling scale.

at
Q_T = 3.5 TeV

for various trial m_0^2 s

when Q_M= 5x10[15] GeV

Case I	$A_t = 0$	$\tan\beta = 50$	$\Delta_{m_0^2} = 85$
m_0^2	$(5\ \mathrm{TeV})^2$	$(4\ \mathrm{TeV})^2$	$(3\ \mathrm{TeV})^2$
$m_{q3}^2(t_T)$	$(5134\ \mathrm{GeV})^2$	$(4107\ \mathrm{GeV})^2$	$(3080\ \mathrm{GeV})^2$
$m_{u_3^c}^2(t_T)$	$(4191\ \mathrm{GeV})^2$	$(3353\ \mathrm{GeV})^2$	$(2515\ \mathrm{GeV})^2$
$\mathbf{m_{h_u}^2(t_T)}$	$-(\mathbf{148}\ \mathrm{GeV})^2$	$-(\mathbf{118}\ \mathrm{GeV})^2$	$-(\mathbf{89}\ \mathrm{GeV})^2$
$m_{h_d}^2(t_T)$	$(3629\ \mathrm{GeV})^2$	$(2903\ \mathrm{GeV})^2$	$(2177\ \mathrm{GeV})^2$
Case II	$A_t = -0.4\ m_0$	$\tan\beta = 50$	$\Delta_{m_0^2} = 27$
m_0^2	$(5\ \mathrm{TeV})^2$	$(4\ \mathrm{TeV})^2$	$(3\ \mathrm{TeV})^2$
$m_{q3}^2(t_T)$	$(5153\ \mathrm{GeV})^2$	$(4123\ \mathrm{GeV})^2$	$(3092\ \mathrm{GeV})^2$
$m_{u_3^c}^2(t_T)$	$(4221\ \mathrm{GeV})^2$	$(3377\ \mathrm{GeV})^2$	$(2533\ \mathrm{GeV})^2$
$\mathbf{m_{h_u}^2(t_T)}$	$(\mathbf{600}\ \mathrm{GeV})^2$	$(\mathbf{480}\ \mathrm{GeV})^2$	$(\mathbf{360}\ \mathrm{GeV})^2$
$m_{h_d}^2(t_T)$	$(3643\ \mathrm{GeV})^2$	$(2915\ \mathrm{GeV})^2$	$(2186\ \mathrm{GeV})^2$
Case III	$A_t = -0.7\ m_0$	$\tan\beta = 50$	$\Delta_{m_0^2} = 74$
m_0^2	$(5\ \mathrm{TeV})^2$	$(4\ \mathrm{TeV})^2$	$(3\ \mathrm{TeV})^2$
$m_{q3}^2(t_T)$	$(5138\ \mathrm{GeV})^2$	$(4111\ \mathrm{GeV})^2$	$(3083\ \mathrm{GeV})^2$
$m_{u_3^c}^2(t_T)$	$(4197\ \mathrm{GeV})^2$	$(3358\ \mathrm{GeV})^2$	$(2518\ \mathrm{GeV})^2$
$\mathbf{m_{h_u}^2(t_T)}$	$(\mathbf{231}\ \mathrm{GeV})^2$	$(\mathbf{185}\ \mathrm{GeV})^2$	$(\mathbf{139}\ \mathrm{GeV})^2$
$m_{h_d}^2(t_T)$	$(3578\ \mathrm{GeV})^2$	$(2862\ \mathrm{GeV})^2$	$(2147\ \mathrm{GeV})^2$
Case IV	$A_t = -0.4\ m_0$	$\tan\beta = 15$	$\Delta_{m_0^2} = 94$
m_0^2	$(5\ \mathrm{TeV})^2$	$(4\ \mathrm{TeV})^2$	$(3\ \mathrm{TeV})^2$
$m_{q3}^2(t_T)$	$(5423\ \mathrm{GeV})^2$	$(4338\ \mathrm{GeV})^2$	$(3254\ \mathrm{GeV})^2$
$m_{u_3^c}^2(t_T)$	$(4212\ \mathrm{GeV})^2$	$(3370\ \mathrm{GeV})^2$	$(2527\ \mathrm{GeV})^2$
$\mathbf{m_{h_u}^2(t_T)}$	$(\mathbf{495}\ \mathrm{GeV})^2$	$(\mathbf{396}\ \mathrm{GeV})^2$	$(\mathbf{297}\ \mathrm{GeV})^2$
$m_{h_d}^2(t_T)$	$(5246\ \mathrm{GeV})^2$	$(4197\ \mathrm{GeV})^2$	$(3148\ \mathrm{GeV})^2$

at

Q_T = 3.5 TeV

for various trial m_0^2 s

when Q_M= 5×10^{15} GeV

Case I	$A_t = 0$	$\tan\beta = 50$	$\mathbf{\Delta_{m_0^2} = 85}$
$\mathbf{m_0^2}$	$(\mathbf{5}\ \mathrm{TeV})^2$	$(\mathbf{4}\ \mathrm{TeV})^2$	$(\mathbf{3}\ \mathrm{TeV})^2$
$m_{q3}^2(t_T)$	$(5134\ \mathrm{GeV})^2$	$(4107\ \mathrm{GeV})^2$	$(3080\ \mathrm{GeV})^2$
$m_{u_3^c}^2(t_T)$	$(4191\ \mathrm{GeV})^2$	$(3353\ \mathrm{GeV})^2$	$(2515\ \mathrm{GeV})^2$
$\mathbf{m_{h_u}^2(t_T)}$	$-(\mathbf{148}\ \mathrm{GeV})^2$	$-(\mathbf{118}\ \mathrm{GeV})^2$	$-(\mathbf{89}\ \mathrm{GeV})^2$
$m_{h_d}^2(t_T)$	$(3629\ \mathrm{GeV})^2$	$(2903\ \mathrm{GeV})^2$	$(2177\ \mathrm{GeV})^2$
Case II	$A_t = -0.4\ m_0$	$\tan\beta = 50$	$\mathbf{\Delta_{m_0^2} = 27}$
$\mathbf{m_0^2}$	$(\mathbf{5}\ \mathrm{TeV})^2$	$(\mathbf{4}\ \mathrm{TeV})^2$	$(\mathbf{3}\ \mathrm{TeV})^2$
$m_{q3}^2(t_T)$	$(5153\ \mathrm{GeV})^2$	$(4123\ \mathrm{GeV})^2$	$(3092\ \mathrm{GeV})^2$
$m_{u_3^c}^2(t_T)$	$(4221\ \mathrm{GeV})^2$	$(3377\ \mathrm{GeV})^2$	$(2533\ \mathrm{GeV})^2$
$\mathbf{m_{h_u}^2(t_T)}$	$(\mathbf{600}\ \mathrm{GeV})^2$	$(\mathbf{480}\ \mathrm{GeV})^2$	$(\mathbf{360}\ \mathrm{GeV})^2$
$m_{h_d}^2(t_T)$	$(3643\ \mathrm{GeV})^2$	$(2915\ \mathrm{GeV})^2$	$(2186\ \mathrm{GeV})^2$
Case III	$A_t = -0.7\ m_0$	$\tan\beta = 50$	$\mathbf{\Delta_{m_0^2} = 74}$
$\mathbf{m_0^2}$	$(\mathbf{5}\ \mathrm{TeV})^2$	$(\mathbf{4}\ \mathrm{TeV})^2$	$(\mathbf{3}\ \mathrm{TeV})^2$
$m_{q3}^2(t_T)$	$(5138\ \mathrm{GeV})^2$	$(4111\ \mathrm{GeV})^2$	$(3083\ \mathrm{GeV})^2$
$m_{u_3^c}^2(t_T)$	$(4197\ \mathrm{GeV})^2$	$(3358\ \mathrm{GeV})^2$	$(2518\ \mathrm{GeV})^2$
$\mathbf{m_{h_u}^2(t_T)}$	$(\mathbf{231}\ \mathrm{GeV})^2$	$(\mathbf{185}\ \mathrm{GeV})^2$	$(\mathbf{139}\ \mathrm{GeV})^2$
$m_{h_d}^2(t_T)$	$(3578\ \mathrm{GeV})^2$	$(2862\ \mathrm{GeV})^2$	$(2147\ \mathrm{GeV})^2$
Case IV	$A_t = -0.4\ m_0$	$\tan\beta = 15$	$\mathbf{\Delta_{m_0^2} = 94}$
$\mathbf{m_0^2}$	$(\mathbf{5}\ \mathrm{TeV})^2$	$(\mathbf{4}\ \mathrm{TeV})^2$	$(\mathbf{3}\ \mathrm{TeV})^2$
$m_{q3}^2(t_T)$	$(5423\ \mathrm{GeV})^2$	$(4338\ \mathrm{GeV})^2$	$(3254\ \mathrm{GeV})^2$
$m_{u_3^c}^2(t_T)$	$(4212\ \mathrm{GeV})^2$	$(3370\ \mathrm{GeV})^2$	$(2527\ \mathrm{GeV})^2$
$\mathbf{m_{h_u}^2(t_T)}$	$(\mathbf{495}\ \mathrm{GeV})^2$	$(\mathbf{396}\ \mathrm{GeV})^2$	$(\mathbf{297}\ \mathrm{GeV})^2$
$m_{h_d}^2(t_T)$	$(5246\ \mathrm{GeV})^2$	$(4197\ \mathrm{GeV})^2$	$(3148\ \mathrm{GeV})^2$

at Q_T = 3.5 TeV

for various trial m_0^2 s

when Q_M= 5×10^{15} GeV

Case I	$A_t = 0$	$\tan\beta = 50$	$\boldsymbol{\Delta}_{\mathbf{m_0^2}} = \mathbf{85}$
$\mathbf{m_0^2}$	$(\mathbf{5}\ \mathrm{TeV})^2$	$(\mathbf{4}\ \mathrm{TeV})^2$	$(\mathbf{3}\ \mathrm{TeV})^2$
$m_{q3}^2(t_T)$	$(5134\ \mathrm{GeV})^2$	$(4107\ \mathrm{GeV})^2$	$(3080\ \mathrm{GeV})^2$
$m_{u_3^c}^2(t_T)$	$(4191\ \mathrm{GeV})^2$	$(3353\ \mathrm{GeV})^2$	$(2515\ \mathrm{GeV})^2$
$\mathbf{m_{h_u}^2(t_T)}$	$-(\mathbf{148}\ \mathrm{GeV})^2$	$-(\mathbf{118}\ \mathrm{GeV})^2$	$-(\mathbf{89}\ \mathrm{GeV})^2$
$m_{h_d}^2(t_T)$	$(3629\ \mathrm{GeV})^2$	$(2903\ \mathrm{GeV})^2$	$(2177\ \mathrm{GeV})^2$

Case II	$A_t = -0.4\ m_0$	$\tan\beta = 50$	$\boldsymbol{\Delta}_{\mathbf{m_0^2}} = \mathbf{27}$
$\mathbf{m_0^2}$	$(\mathbf{5}\ \mathrm{TeV})^2$	$(\mathbf{4}\ \mathrm{TeV})^2$	$(\mathbf{3}\ \mathrm{TeV})^2$
$m_{q3}^2(t_T)$	$(5153\ \mathrm{GeV})^2$	$(4123\ \mathrm{GeV})^2$	$(3092\ \mathrm{GeV})^2$
$m_{u_3^c}^2(t_T)$	$(4221\ \mathrm{GeV})^2$	$(3377\ \mathrm{GeV})^2$	$(2533\ \mathrm{GeV})^2$
$\mathbf{m_{h_u}^2(t_T)}$	$(\mathbf{600}\ \mathrm{GeV})^2$	$(\mathbf{480}\ \mathrm{GeV})^2$	$(\mathbf{360}\ \mathrm{GeV})^2$
$m_{h_d}^2(t_T)$	$(3643\ \mathrm{GeV})^2$	$(2915\ \mathrm{GeV})^2$	$(2186\ \mathrm{GeV})^2$

Case III	$A_t = -0.7\ m_0$	$\tan\beta = 50$	$\boldsymbol{\Delta}_{\mathbf{m_0^2}} = \mathbf{74}$
$\mathbf{m_0^2}$	$(\mathbf{5}\ \mathrm{TeV})^2$	$(\mathbf{4}\ \mathrm{TeV})^2$	$(\mathbf{3}\ \mathrm{TeV})^2$
$m_{q3}^2(t_T)$	$(5138\ \mathrm{GeV})^2$	$(4111\ \mathrm{GeV})^2$	$(3083\ \mathrm{GeV})^2$
$m_{u_3^c}^2(t_T)$	$(4197\ \mathrm{GeV})^2$	$(3358\ \mathrm{GeV})^2$	$(2518\ \mathrm{GeV})^2$
$\mathbf{m_{h_u}^2(t_T)}$	$(\mathbf{231}\ \mathrm{GeV})^2$	$(\mathbf{185}\ \mathrm{GeV})^2$	$(\mathbf{139}\ \mathrm{GeV})^2$
$m_{h_d}^2(t_T)$	$(3578\ \mathrm{GeV})^2$	$(2862\ \mathrm{GeV})^2$	$(2147\ \mathrm{GeV})^2$

Case IV	$A_t = -0.4\ m_0$	$\tan\beta = 15$	$\boldsymbol{\Delta}_{\mathbf{m_0^2}} = \mathbf{94}$
$\mathbf{m_0^2}$	$(\mathbf{5}\ \mathrm{TeV})^2$	$(\mathbf{4}\ \mathrm{TeV})^2$	$(\mathbf{3}\ \mathrm{TeV})^2$
$m_{q3}^2(t_T)$	$(5423\ \mathrm{GeV})^2$	$(4338\ \mathrm{GeV})^2$	$(3254\ \mathrm{GeV})^2$
$m_{u_3^c}^2(t_T)$	$(4212\ \mathrm{GeV})^2$	$(3370\ \mathrm{GeV})^2$	$(2527\ \mathrm{GeV})^2$
$\mathbf{m_{h_u}^2(t_T)}$	$(\mathbf{495}\ \mathrm{GeV})^2$	$(\mathbf{396}\ \mathrm{GeV})^2$	$(\mathbf{297}\ \mathrm{GeV})^2$
$m_{h_d}^2(t_T)$	$(5246\ \mathrm{GeV})^2$	$(4197\ \mathrm{GeV})^2$	$(3148\ \mathrm{GeV})^2$

at Q_T = 3.5 TeV

for various trial m_0^2 s

when Q_M= 5x10^{15} GeV

Case I	$A_t = 0$	$\tan\beta = 50$	$\Delta_{m_0^2} = 85$
$\mathbf{m_0^2}$	$(\mathbf{5}\ \mathrm{TeV})^2$	$(\mathbf{4}\ \mathrm{TeV})^2$	$(\mathbf{3}\ \mathrm{TeV})^2$
$m^2_{q_3}(t_T)$	$(5134\ \mathrm{GeV})^2$	$(4107\ \mathrm{GeV})^2$	$(3080\ \mathrm{GeV})^2$
$m^2_{u_3^c}(t_T)$	$(4191\ \mathrm{GeV})^2$	$(3353\ \mathrm{GeV})^2$	$(2515\ \mathrm{GeV})^2$
$\mathbf{m^2_{h_u}(t_T)}$	$-(\mathbf{148}\ \mathrm{GeV})^2$	$-(\mathbf{118}\ \mathrm{GeV})^2$	$-(\mathbf{89}\ \mathrm{GeV})^2$
$m^2_{h_d}(t_T)$	$(3629\ \mathrm{GeV})^2$	$(2903\ \mathrm{GeV})^2$	$(2177\ \mathrm{GeV})^2$
Case II	$A_t = -0.4\ m_0$	$\tan\beta = 50$	$\Delta_{m_0^2} = 27$
$\mathbf{m_0^2}$	$(\mathbf{5}\ \mathrm{TeV})^2$	$(\mathbf{4}\ \mathrm{TeV})^2$	$(\mathbf{3}\ \mathrm{TeV})^2$
$m^2_{q_3}(t_T)$	$(5153\ \mathrm{GeV})^2$	$(4123\ \mathrm{GeV})^2$	$(3092\ \mathrm{GeV})^2$
$m^2_{u_3^c}(t_T)$	$(4221\ \mathrm{GeV})^2$	$(3377\ \mathrm{GeV})^2$	$(2533\ \mathrm{GeV})^2$
$\mathbf{m^2_{h_u}(t_T)}$	$(\mathbf{600}\ \mathrm{GeV})^2$	$(\mathbf{480}\ \mathrm{GeV})^2$	$(\mathbf{360}\ \mathrm{GeV})^2$
$m^2_{h_d}(t_T)$	$(3643\ \mathrm{GeV})^2$	$(2915\ \mathrm{GeV})^2$	$(2186\ \mathrm{GeV})^2$
Case III	$A_t = -0.7\ m_0$	$\tan\beta = 50$	$\Delta_{m_0^2} = 74$
$\mathbf{m_0^2}$	$(\mathbf{5}\ \mathrm{TeV})^2$	$(\mathbf{4}\ \mathrm{TeV})^2$	$(\mathbf{3}\ \mathrm{TeV})^2$
$m^2_{q_3}(t_T)$	$(5138\ \mathrm{GeV})^2$	$(4111\ \mathrm{GeV})^2$	$(3083\ \mathrm{GeV})^2$
$m^2_{u_3^c}(t_T)$	$(4197\ \mathrm{GeV})^2$	$(3358\ \mathrm{GeV})^2$	$(2518\ \mathrm{GeV})^2$
$\mathbf{m^2_{h_u}(t_T)}$	$(\mathbf{231}\ \mathrm{GeV})^2$	$(\mathbf{185}\ \mathrm{GeV})^2$	$(\mathbf{139}\ \mathrm{GeV})^2$
$m^2_{h_d}(t_T)$	$(3578\ \mathrm{GeV})^2$	$(2862\ \mathrm{GeV})^2$	$(2147\ \mathrm{GeV})^2$
Case IV	$A_t = -0.4\ m_0$	$\tan\beta = 15$	$\Delta_{m_0^2} = 94$
$\mathbf{m_0^2}$	$(\mathbf{5}\ \mathrm{TeV})^2$	$(\mathbf{4}\ \mathrm{TeV})^2$	$(\mathbf{3}\ \mathrm{TeV})^2$
$m^2_{q_3}(t_T)$	$(5423\ \mathrm{GeV})^2$	$(4338\ \mathrm{GeV})^2$	$(3254\ \mathrm{GeV})^2$
$m^2_{u_3^c}(t_T)$	$(4212\ \mathrm{GeV})^2$	$(3370\ \mathrm{GeV})^2$	$(2527\ \mathrm{GeV})^2$
$\mathbf{m^2_{h_u}(t_T)}$	$(\mathbf{495}\ \mathrm{GeV})^2$	$(\mathbf{396}\ \mathrm{GeV})^2$	$(\mathbf{297}\ \mathrm{GeV})^2$
$m^2_{h_d}(t_T)$	$(5246\ \mathrm{GeV})^2$	$(4197\ \mathrm{GeV})^2$	$(3148\ \mathrm{GeV})^2$

Fine-Tuning Measures

For $m_0^2 = (4\,\mathrm{TeV})^2$ and

$$-0.5 \lesssim A_t/m_0 \lesssim 0$$

both $\Delta_{m_0^2}$ and Δ_{A_t} $\ll 100$

$$\equiv \left|\frac{\partial \log m_Z^2}{\partial \log m_0^2}\right| = \left|\frac{m_0^2}{m_Z^2}\frac{\partial m_Z^2}{\partial m_0^2}\right| \qquad = \left|\frac{A_t}{m_Z^2}\frac{\partial m_Z^2}{\partial A_t}\right|$$

Fine-Tuning Measures

Even for

For $m_0^2 = (4\,\mathrm{TeV})^2$ → $(m_{q_3}^2, m_{u_3^c}^2) =$ **3 – 4 TeV**

$$-0.5 \lesssim A_t/m_0 \lesssim 0$$

both $\Delta_{m_0^2}$ and Δ_{A_t} $\ll 100$

$$\equiv \left|\frac{\partial \log m_Z^2}{\partial \log m_0^2}\right| = \left|\frac{m_0^2}{m_Z^2}\frac{\partial m_Z^2}{\partial m_0^2}\right| \qquad = \left|\frac{A_t}{m_Z^2}\frac{\partial m_Z^2}{\partial A_t}\right|$$

SUSY particle masses

For $m_0^2 = (4\,\mathrm{TeV})^2$ and

$$-0.5 \lesssim A_t/m_0 \lesssim 0$$

$$(m^2_{q_3}, m^2_{u^c_3}) = \text{3 – 4 TeV}$$

responsible for

126 GeV Higgs mass

$$M_a(t_T) \approx 0.57 \times m_0 \times g_a^2(t_T)$$

SUSY particle masses

For $m_0^2 = (4\,\mathrm{TeV})^2$ and

$$-0.5 \lesssim A_t/m_0 \lesssim 0$$

$$(m_{q_3}^2, m_{u_3^c}^2) = $$ **3 – 4 TeV**

responsible for

126 GeV Higgs mass

$$M_{3,2,1} \approx \{\underline{2.3\,\mathrm{TeV}},\ 912\,\mathrm{GeV},\ 504\,\mathrm{GeV}\}$$

PREDICTIONS !

testable at LHC run2

SUSY particle masses

For $m_0^2 = (4\,\mathrm{TeV})^2$ and

$$-0.5 \lesssim A_t/m_0 \lesssim 0$$

$(m_{q_3}^2, m_{u_3^c}^2) = $ **3 – 4 TeV** responsible for 126 GeV Higgs mass

$$M_{3,2,1} \approx \{\underline{2.3\,\mathrm{TeV}},\ 912\,\mathrm{GeV},\ 504\,\mathrm{GeV}\}$$

sleptons , sbottom masses > 3 – 4 TeV

SUSY particle masses

For $m_0^2 = (4\,\mathrm{TeV})^2$ and

$$-0.5 \lesssim A_t/m_0 \lesssim 0$$

$(m_{q_3}^2, m_{u_3^c}^2) =$ **3 – 4 TeV** responsible for 126 GeV Higgs mass

$$M_{3,2,1} \approx \{\underline{2.3\,\mathrm{TeV},}\ 912\,\mathrm{GeV},\ 504\,\mathrm{GeV}\}$$

$|\mu|$ = 330 GeV – 590 GeV for m_Z = 91 GeV

SUSY particle masses

For $M_1 < |\mu|$ $(M_1 > |\mu|)$, **Bino (Higgsino) is the LSP.**

Some entropy production needed

Some other DM component needed

Conclusion

- minimal Gravity medi. + minimal Gauge medi.
  = precise focusing of m_{hu}^2 around stop mass scale.

- m_{hu}^2 is insensitive to trial m_0^2 or heavy stop masses.

- m_0^2 happens to be $\approx (4\ \text{TeV})^2$, *which yields*
  3-4 TeV stop and 126 GeV Higgs masses.

Conclusion

- The fine-tuning measures significantly decrease well-below 100 even for 3-4 TeV stop masses.
  $\longrightarrow$ predictively small EW scale

- The fine-tuning associated with zero C.C. would be responsible for the fine-tuning required in the little hierarchy problem ($F_S = m_0 M_P$).

- Gluino mass is predicted to be about 2.3 TeV.
  $\longrightarrow$ it could readily tested at LHC run2.

at

Q_T = 3.5 TeV

for various trial m_0^2 s

when Q_M= 5×10^{15} GeV

Case I	$A_t = 0$	$\tan\beta = 50$	$\Delta_{m_0^2} = 85$
$\mathbf{m_0^2}$	$(\mathbf{5}\ \text{TeV})^2$	$(\mathbf{4}\ \text{TeV})^2$	$(\mathbf{3}\ \text{TeV})^2$
$m^2_{q_3}(t_T)$	$(5134\ \text{GeV})^2$	$(4107\ \text{GeV})^2$	$(3080\ \text{GeV})^2$
$m^2_{u^c_3}(t_T)$	$(4191\ \text{GeV})^2$	$(3353\ \text{GeV})^2$	$(2515\ \text{GeV})^2$
$\mathbf{m^2_{h_u}(t_T)}$	$-(\mathbf{148}\ \text{GeV})^2$	$-(\mathbf{118}\ \text{GeV})^2$	$-(\mathbf{89}\ \text{GeV})^2$
$m^2_{h_d}(t_T)$	$(3629\ \text{GeV})^2$	$(2903\ \text{GeV})^2$	$(2177\ \text{GeV})^2$
Case II	$A_t = -0.4\ m_0$	$\tan\beta = 50$	$\Delta_{m_0^2} = 27$
$\mathbf{m_0^2}$	$(\mathbf{5}\ \text{TeV})^2$	$(\mathbf{4}\ \text{TeV})^2$	$(\mathbf{3}\ \text{TeV})^2$
$m^2_{q_3}(t_T)$	$(5153\ \text{GeV})^2$	$(4123\ \text{GeV})^2$	$(3092\ \text{GeV})^2$
$m^2_{u^c_3}(t_T)$	$(4221\ \text{GeV})^2$	$(3377\ \text{GeV})^2$	$(2533\ \text{GeV})^2$
$\mathbf{m^2_{h_u}(t_T)}$	$(\mathbf{600}\ \text{GeV})^2$	$(\mathbf{480}\ \text{GeV})^2$	$(\mathbf{360}\ \text{GeV})^2$
$m^2_{h_d}(t_T)$	$(3643\ \text{GeV})^2$	$(2915\ \text{GeV})^2$	$(2186\ \text{GeV})^2$
Case III	$A_t = -0.7\ m_0$	$\tan\beta = 50$	$\Delta_{m_0^2} = 74$
$\mathbf{m_0^2}$	$(\mathbf{5}\ \text{TeV})^2$	$(\mathbf{4}\ \text{TeV})^2$	$(\mathbf{3}\ \text{TeV})^2$
$m^2_{q_3}(t_T)$	$(5138\ \text{GeV})^2$	$(4111\ \text{GeV})^2$	$(3083\ \text{GeV})^2$
$m^2_{u^c_3}(t_T)$	$(4197\ \text{GeV})^2$	$(3358\ \text{GeV})^2$	$(2518\ \text{GeV})^2$
$\mathbf{m^2_{h_u}(t_T)}$	$(\mathbf{231}\ \text{GeV})^2$	$(\mathbf{185}\ \text{GeV})^2$	$(\mathbf{139}\ \text{GeV})^2$
$m^2_{h_d}(t_T)$	$(3578\ \text{GeV})^2$	$(2862\ \text{GeV})^2$	$(2147\ \text{GeV})^2$
Case IV	$A_t = -0.4\ m_0$	$\tan\beta = 15$	$\Delta_{m_0^2} = 94$
$\mathbf{m_0^2}$	$(\mathbf{5}\ \text{TeV})^2$	$(\mathbf{4}\ \text{TeV})^2$	$(\mathbf{3}\ \text{TeV})^2$
$m^2_{q_3}(t_T)$	$(5423\ \text{GeV})^2$	$(4338\ \text{GeV})^2$	$(3254\ \text{GeV})^2$
$m^2_{u^c_3}(t_T)$	$(4212\ \text{GeV})^2$	$(3370\ \text{GeV})^2$	$(2527\ \text{GeV})^2$
$\mathbf{m^2_{h_u}(t_T)}$	$(\mathbf{495}\ \text{GeV})^2$	$(\mathbf{396}\ \text{GeV})^2$	$(\mathbf{297}\ \text{GeV})^2$
$m^2_{h_d}(t_T)$	$(5246\ \text{GeV})^2$	$(4197\ \text{GeV})^2$	$(3148\ \text{GeV})^2$

[Feng, etal., PRL (2013)]