Shifted Focus Point and Naturalness-guided Gluino Mass Bound

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1. **arXiv: 1502.02311**
2. **arXiv: 1507.07611**

collaborated with Doyoun Kim (APCTP)

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- 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, which is too heavy as a SUSY Higgs.

- 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)]

$$\Delta m_{h_u}^2|_{1-\text{loop}} \approx \frac{3|y_t|^2}{8\pi^2}\widetilde{m}_t^2 \log\left(\frac{\widetilde{m}_t^2}{\Lambda^2}\right)\left[1+\frac{1}{2}\frac{A_t^2}{\widetilde{m}_t^2}\right],$$

$$\Delta m_H^2|_{1-\text{loop}} \approx \frac{3m_t^4}{4\pi^2 v_h^2}\left[\log\left(\frac{\widetilde{m}_t^2}{m_t^2}\right)+\frac{A_t^2}{\widetilde{m}_t^2}\left(1-\frac{1}{12}\frac{A_t^2}{\widetilde{m}_t^2}\right)\right],$$

$$\frac{1}{2}m_Z^2 = \frac{m_{h_d}^2 - m_{h_u}^2\tan^2\beta}{\tan^2\beta - 1} - |\mu|^2.$$

- ATLAS and CMS have discovered the SM(-like) Higgs with 125-126 GeV mass, which is too heavy as a SUSY Higgs.
- 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.

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

We will propose a scenario, in which

the Gluino Mass is more closely associated with the Naturalness.

Focus Point scenario

[Feng, Matchev, Moroi (2000)]

Suppose that

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

   at the GUT scale

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

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

Focus Point scenario

With the Minimal Gravity Mediation , i.e. with the Universal soft masses

$$m_{h_u}^2(Q=m_Z) = C_s m_0^2 - C_g m_{1/2}^2$$

$C_s,\ C_g\ (>0)$

C_s happens to be **small**.

Focus Point scenario

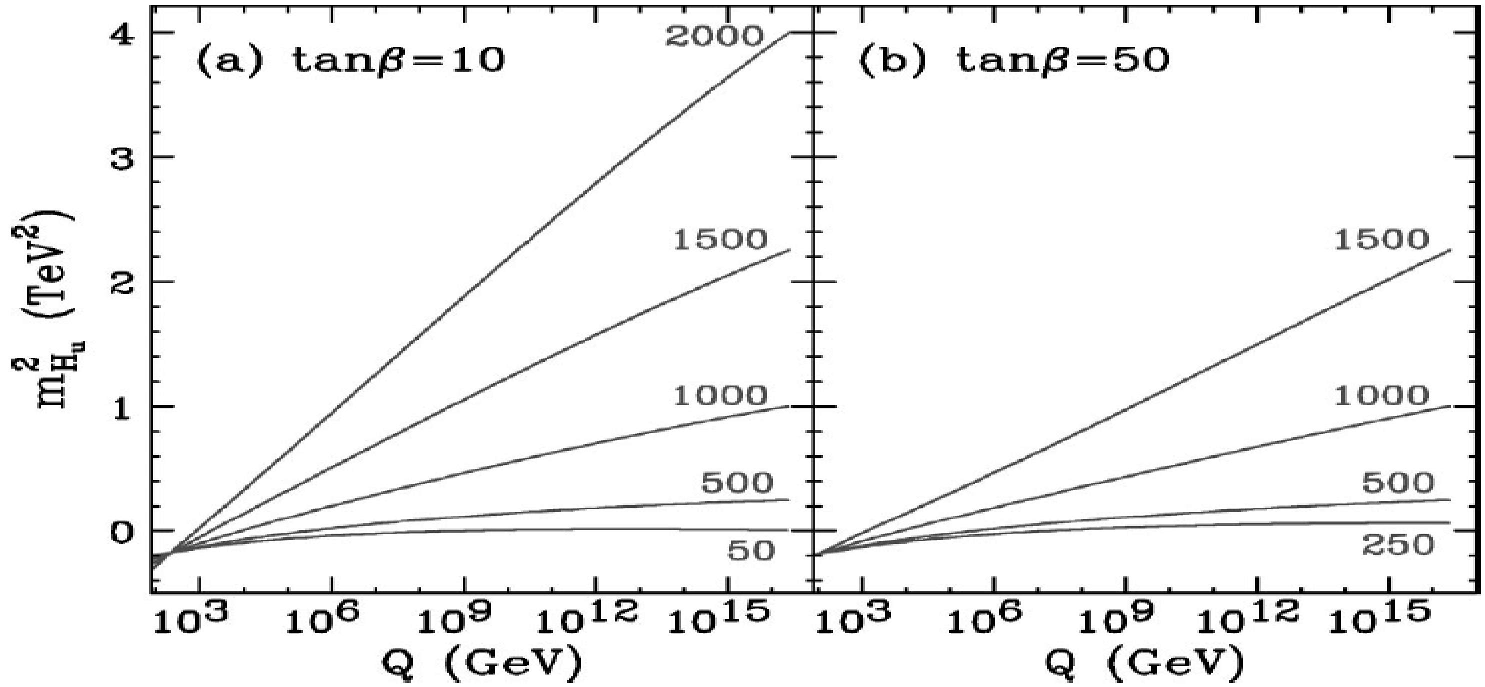
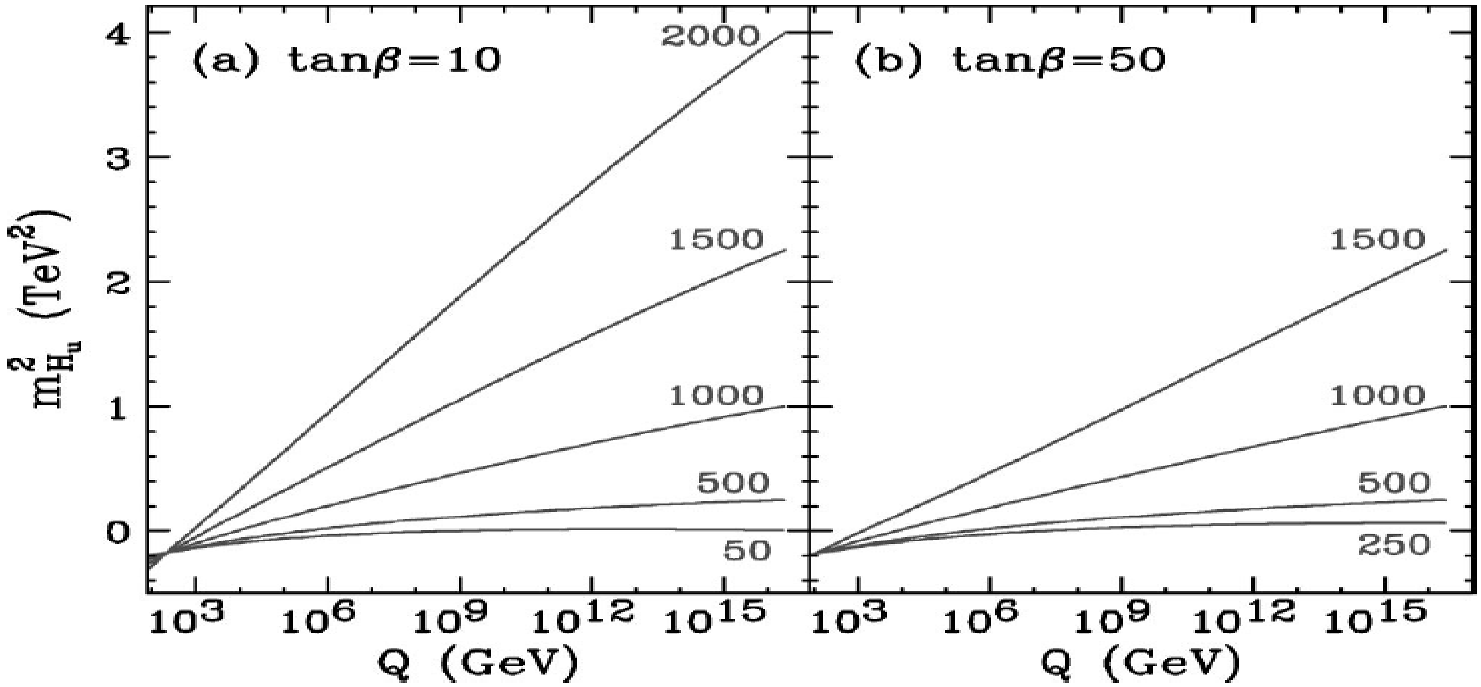


FIG. 1. The RG evolution of $m^2_{H_u}$ for (a) $\tan\beta = 10$ and (b) $\tan\beta = 50$, several values of m_0 (shown, in GeV), $M_{1/2} = 300$ GeV, $A_0 = 0$, and $m_t = 174$ GeV. For both values of $\tan\beta$, $m^2_{H_u}$ exhibits an RG focus point near the weak scale, where $Q_F^{(H_u)} \sim \mathcal{O}(100$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

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?

Challenges

from experiments

In the Minimal Gravity Mediation,

$$m_{h_u}^2(Q = m_Z) = C_s m_0^2 - C_g m_{1/2}^2$$

$C_s,\ C_g\ (> 0)$

Since $M_3 > 1.4$ TeV ,

$m_{1/2}$ can NOT be small.

Challenges

from experiments

In the Minimal Gravity Mediation,

$$m_{h_u}^2(Q = m_Z) = C_s m_0^2 - C_g m_{1/2}^2$$

Since $M_3 > 1.4$ TeV ,

$C_s,\ C_g\ (> 0)$

$m_{1/2}$ can NOT be small.

μ should be LARGE → Fine-tuning if stop mass < 1 TeV

Challenges
from theory

In the Minimal Gravity Mediation,

$$m_{h_u}^2(Q = m_Z) = C_s m_0^2 - C_g m_{1/2}^2$$

$C_s,\ C_g\ (> 0)$

For stop mass = 3-4 TeV ,

C_s becomes **sizable**.

Challenges

from theory

In the Minimal Gravity Mediation,

$$m_{h_u}^2(Q=m_Z) = C_s m_0^2 - C_g m_{1/2}^2$$

$C_s,\ C_g\ (>0)$

For stop mass = 3-4 TeV ,

C_s becomes sizable.

The FP behavior becomes seriously **spoiled** for stop mass =3-4 TeV

Challenges
from theory

In the Minimal Gravity Mediation,

$$m_{h_u}^2(Q = m_Z) = C_s m_0^2 - C_g m_{1/2}^2$$

$C_s,\ C_g\ (> 0)$

For stop mass = 3-4 TeV ,

C_s becomes sizable.

$C_g m_{1/2}^2$ should also be large for EW sym. breaking.

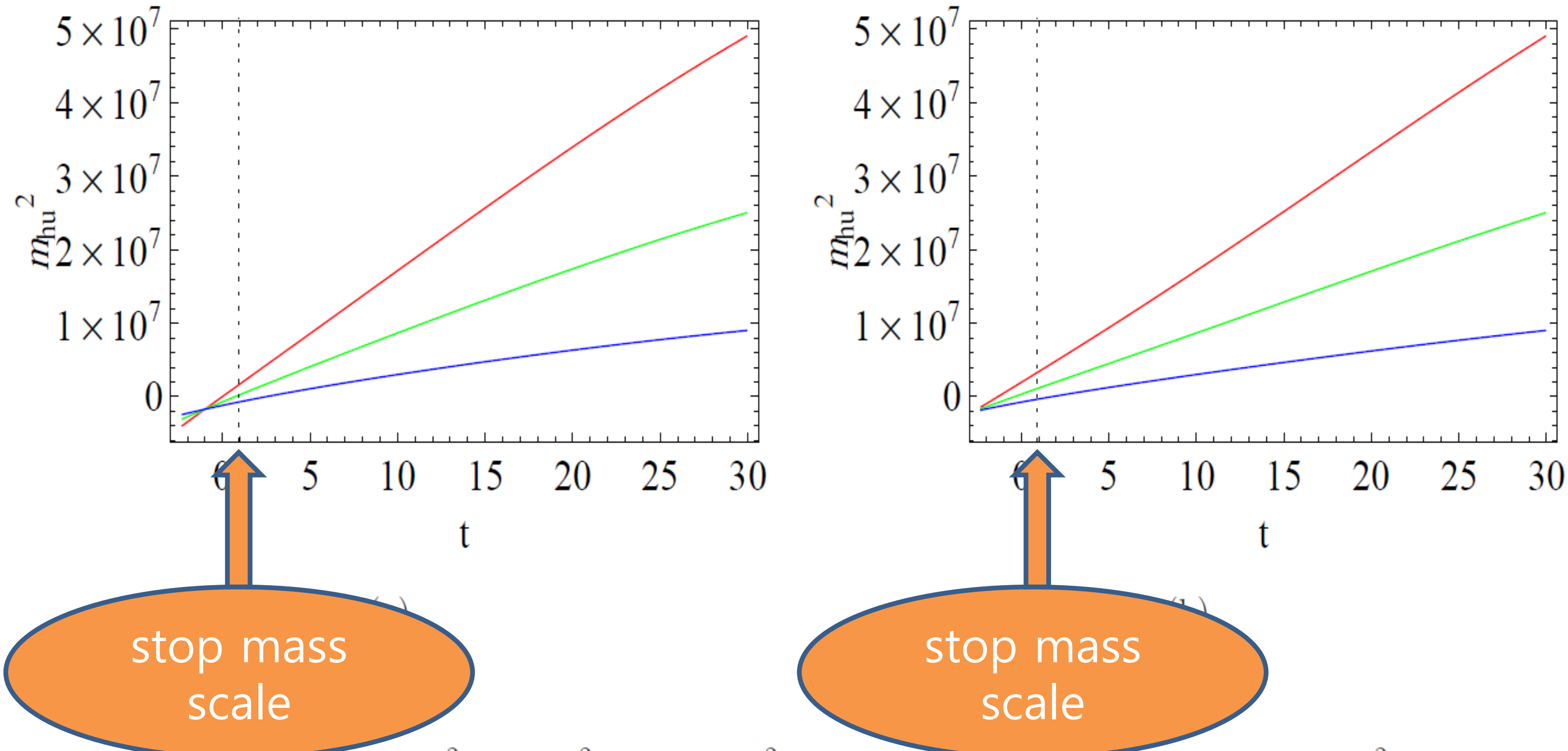
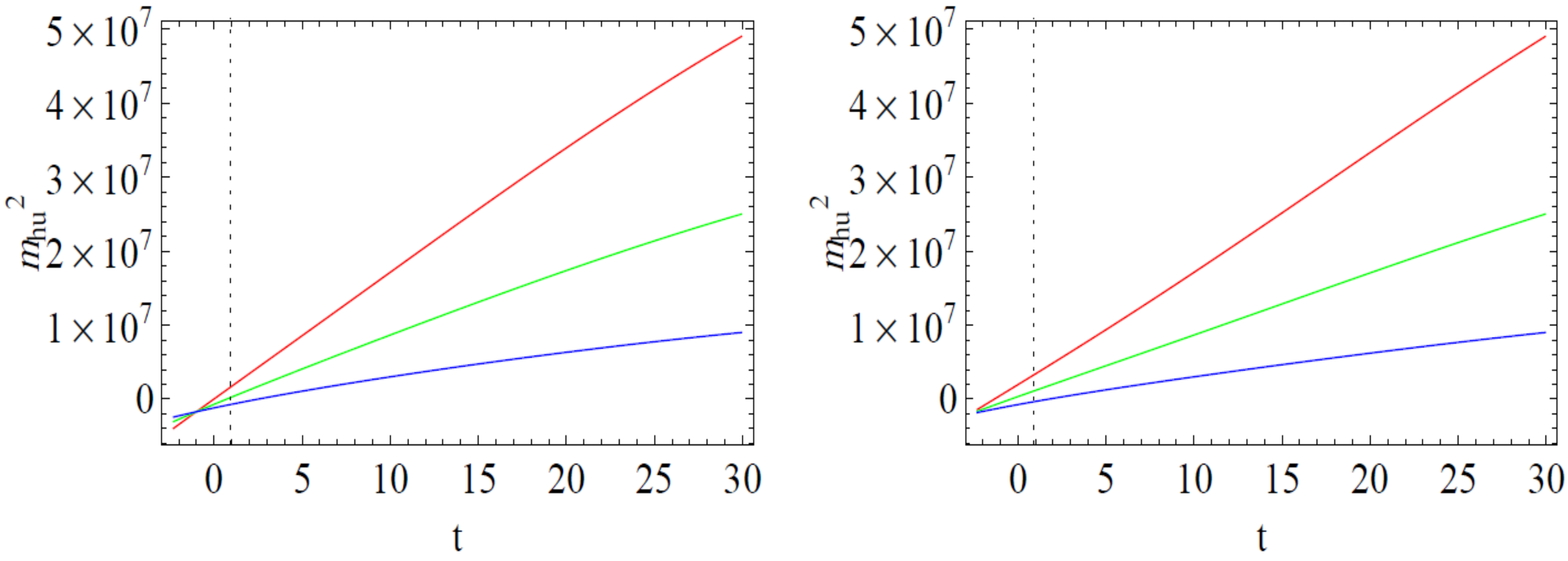


FIG. 1: RG evolutions of $m_{h_u}^2$ for $m_0^2 = (7\,\mathrm{TeV})^2$ [Red], $(5\,\mathrm{TeV})^2$ [Green], and $(3\,\mathrm{TeV})^2$ [Blue], and for **(a)** $\tan\beta = 5$ and **(b)** $\tan\beta = 50$, when $m_{1/2} = 1\,\mathrm{TeV}$ and $A_0 = 0$. Here we take $\alpha_G = 1/25$. The unit of the vertical axis is $(\mathrm{GeV})^2$. The dotted lines at $t \approx 0.92$ denote the assumed stop decoupling scale, $Q = 5\,\mathrm{TeV}$. $t \approx -2.3$ [$t \approx 29.9$] corresponds to $Q = 200\,\mathrm{GeV}$ [$Q = 2\times10^{16}\,\mathrm{GeV}$]. 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) $\tan\beta$.



(a) (b)

FIG. 1: I … ue], and for **(a)** t … = 1/25. The unit … ed stop

$$\Delta_{m_0^2} = \left| \frac{\partial \log m_Z^2}{\partial \log m_0^2} \right| = \left| \frac{m_0^2}{m_Z^2} \frac{\partial m_Z^2}{\partial m_0^2} \right| \sim \mathbf{O(10^{2\text{-}3})}$$

decoupling scale, $Q = 5$ TeV. $t \approx -2.3$ [$t \approx 29.9$] corresponds to $Q = 200$ GeV [$Q = 2 \times 10^{16}$ 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

In the Minimal Gravity Mediation,

$$m_{h_u}^2(Q = m_Z) = C_s m_0^2 - C_g m_{1/2}^2$$

$C_s,\ C_g\ (> 0)$

C_s needs to be made

SMAll enough

before stop decoupled.

For predictively small EW scale

In the Minimal Gravity Mediation,

$$m_{h_u}^2(Q=m_Z) = C_s m_0^2 - C_g m_{1/2}^2$$

$C_s,\ C_g\ (>0)$

$C_g m_{1/2}^2$ needs to be SMAll enough for a small μ.

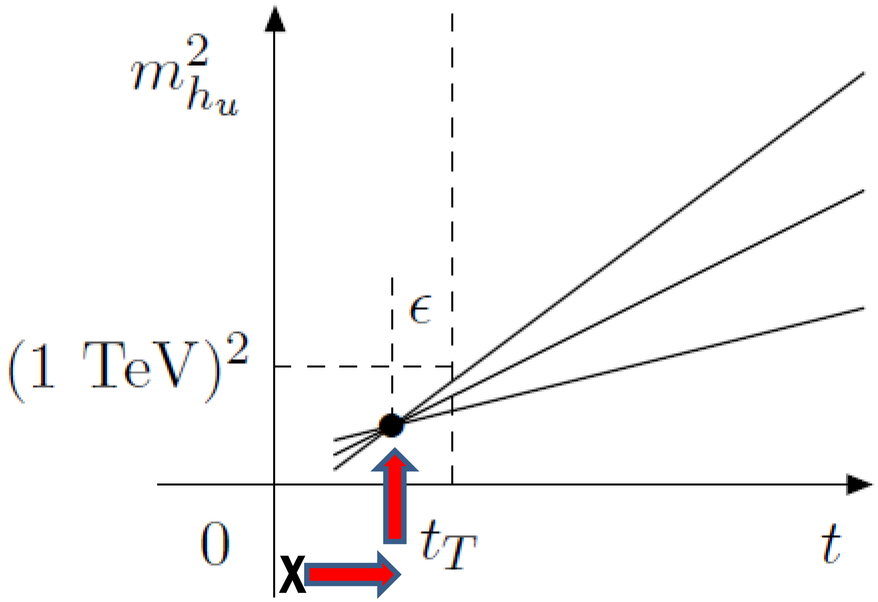
Below the stop mass scale

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

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

m_{hu}^2 further decreases by $\sim$(530 GeV)^2 from Q = 3-4 TeV to Q = M_Z.

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.

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

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 Mixed Medation*"

Minimal Gravity Mediation

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

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

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

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

Minimal Gravity Mediation

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

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

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

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

$\langle F_{z_i} \rangle \sim O(mM_P)$

Minimal Gravity Mediation

With the minimal Kahler pot. K, and superpot. W,
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. K, and superpot. W,

where the Hidden and Observ. Sectors are separated,

For the *vanishing* Cosmological Constant,

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

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

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

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

Minimal Gravity Mediation

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

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

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

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

Minimal Gravity Mediation

With the minimal Kahler pot. K, and superpot. W,

where the Hidden and Observ. Sectors are separated,

Universal Soft Masses:

$$m^2_{h_u} = m^2_{h_d} = m^2_{q_3} = m^2_{u^c_3} = \cdots = m^2_0$$

A-terms ∝ m_0

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

$$\langle z_i \rangle \quad = a_i mM_P, \ \langle W_H \rangle = mM_P^2,$$

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

Minimal Gravity Mediation

With the minimal Kahler pot. K, and superpot. W,

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*

Assume

$f_{ab} = \delta_{ab}$

So **$M_a = 0$**

at tree level.

$$\langle z_i \rangle \cdots = a_i mM_P, \; \langle \cdots$$

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

Minimal Gravity Mediation

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

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

$$f_{ab} = \delta_{ab}$$

$$\frac{M_P}{4}\, e^{G/(2M_P^2)}\, \frac{\partial f^*_{ab}}{\partial z^*_i}\, \frac{\partial G}{\partial z_i}\, \lambda^a \lambda^b = \frac{1}{4} e^{\sum_i |b_i|^2/2}\, \frac{\partial f^*_{ab}}{\partial z^*_i}\, F_{z_i}\, \lambda^a \lambda^b$$

Minimal Gauge Mediation

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

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

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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**} ,

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

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

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

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

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

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

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

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

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

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

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

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

Minimal Gauge Mediation

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

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

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

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

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

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

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

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

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

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

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

$M_G \approx 1.3 \times 10^{16}$ GeV

where $C_a(i)$ is the qu… $(T^a \ldots)_i \ldots$

Minimal **Gauge** Mediation

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

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

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

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

$$f_G \cdot m_0 \equiv \frac{\langle F_S \rangle}{16\pi^2 \langle S \rangle} = \frac{m_0 M_P}{16\pi^2 M_X} \sqrt{\frac{5}{24}} g_G \approx 0.36\, m_0$$

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

Minimal Mixed Mediation

In the Minimal Mixed Mediation,

$$m_{h_u}^2(Q = m_Z) = C_s m_0^2 - C_g m_{1/2}^2$$

$C_s,\ C_g\ (> 0)$

As C_g is converted to a C_s, making C_s smaller,

Fine-Tuning is improved,

until the FP reaches the stop decoupling scale.

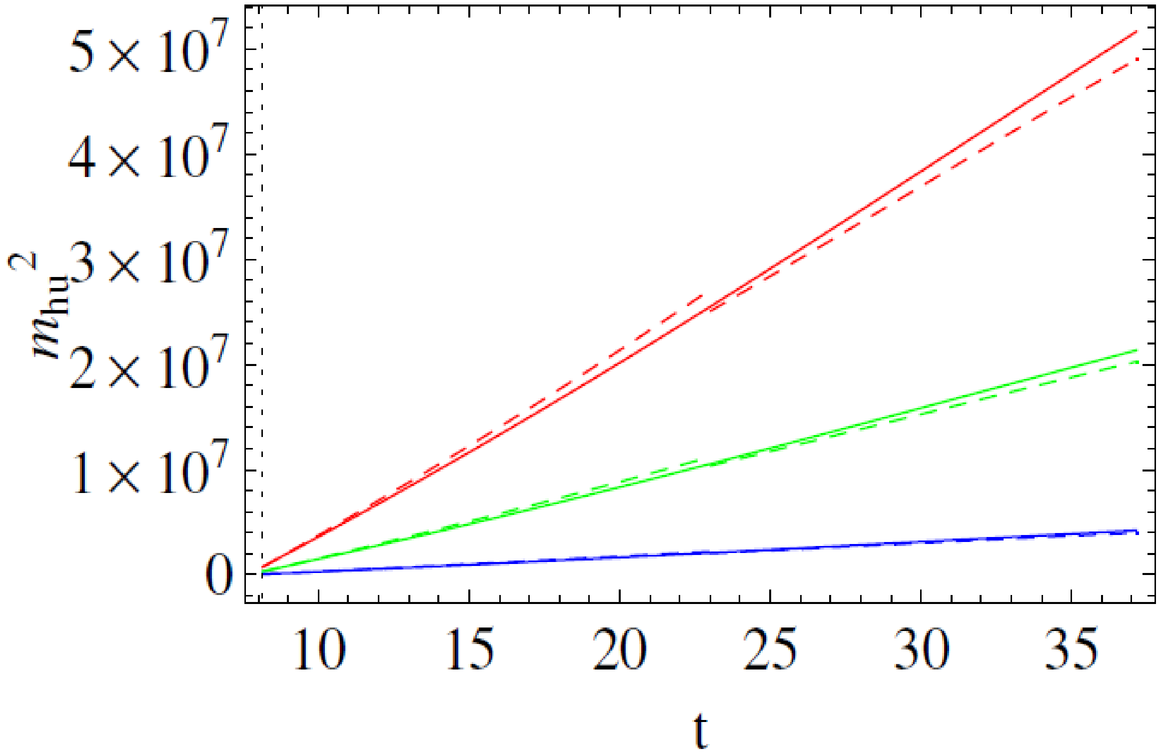
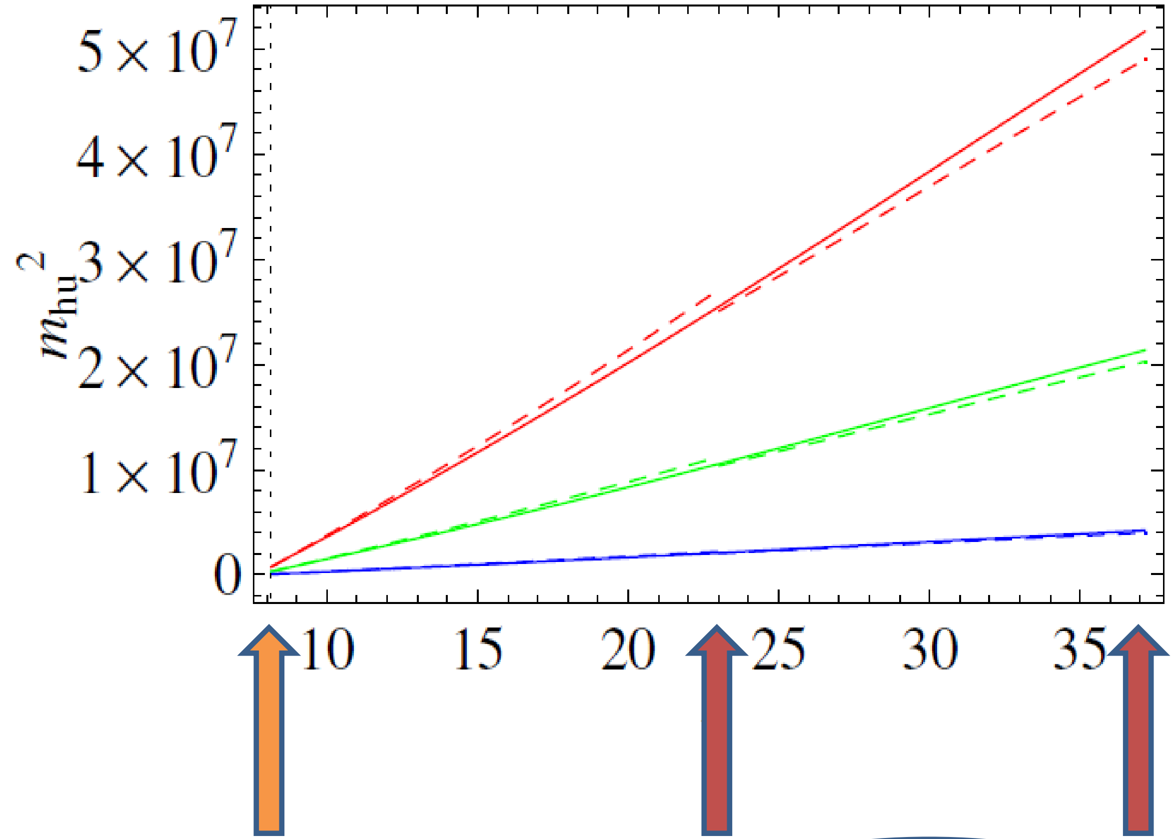


FIG. 1. RG evolutions of $m^2_{h_u}$ with t [$\equiv \log(Q/\,\text{GeV})$] for $m_0^2 = (7\,\text{TeV})^2$ [Red], $(4.5\,\text{TeV})^2$ [Green], and $(2\,\text{TeV})^2$ [Blue] when $A_t = -0.2\ m_0$ and $\tan\beta = 50$. The tilted straight [dotted] lines correspond to the case of $t_M \approx 37$ (or $Q_M \approx 1.3\times10^{16}$ GeV, "Case A") [$t_M \approx 23$ (or $Q_M = 1.0\times10^{10}$ 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. The discontinuities of $m^2_{h_u}(t)$ should appear at the messenger scales.



stop mass scale

messenger scales

FIG[...] $m^2_{h_u}$ w[...]or m_0^2 = [...]TeV)^2 [Gr[...]blue] when $A_t = -0.2\, m_0$ and $\tan\beta = 50$. The tilted straight [dotted] lines correspond to the case of $t_M \approx 37$ (or $Q_M \approx 1.3\times10^{16}$ GeV, "Case A") [$t_M \approx 23$ (or $Q_M = 1.0\times10^{10}$ 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. The discontinuities of $m^2_{h_u}(t)$ should appear at the messenger scales.

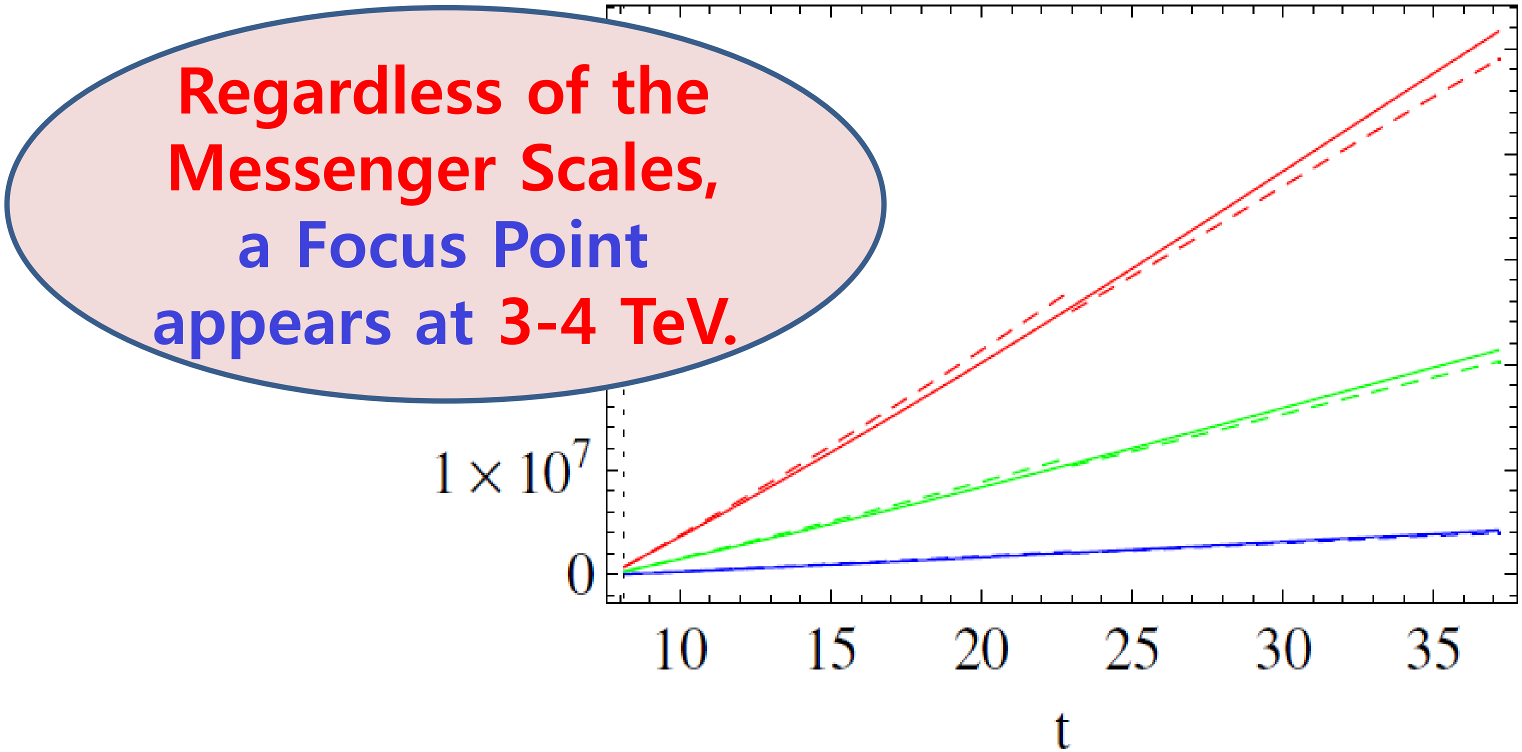


FIG. 1. RG evolutions of $m^2_{h_u}$ with t [$\equiv \log(Q/\,\mathrm{GeV})$] for $m_0^2 = (7\,\mathrm{TeV})^2$ [Red], $(4.5\,\mathrm{TeV})^2$ [Green], and $(2\,\mathrm{TeV})^2$ [Blue] when $A_t = -0.2\ m_0$ and $\tan\beta = 50$. The tilted straight [dotted] lines correspond to the case of $t_M \approx 37$ (or $Q_M \approx 1.3\times10^{16}$ GeV, "Case A") [$t_M \approx 23$ (or $Q_M = 1.0\times10^{10}$ 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. The discontinuities of $m^2_{h_u}(t)$ should appear at the messenger scales.

at
Q_T = 3.5 TeV

for various trial m_0^2 s

when $Q_M \approx 1.3 \times 10^{16}$ GeV

Case I	$A_t = 0$	$\tan\beta = 50$	$\Delta_{m_0^2} = 1$
m_0^2	$(5.5\ \text{TeV})^2$	$(4.5\ \text{TeV})^2$	$(3.5\ \text{TeV})^2$
$m_{q3}^2(t_T)$	$(4363\ \text{GeV})^2$	$(3551\ \text{GeV})^2$	$(2744\ \text{GeV})^2$
$m_{u_3^c}^2(t_T)$	$(3789\ \text{GeV})^2$	$(3098\ \text{GeV})^2$	$(2406\ \text{GeV})^2$
$m_{h_u}^2(t_T)$	$(431\ \text{GeV})^2$	$(189\ \text{GeV})^2$	$-(251\ \text{GeV})^2$
$m_{h_d}^2(t_T)$	$(2022\ \text{GeV})^2$	$(1512\ \text{GeV})^2$	$(1008\ \text{GeV})^2$
Case II	$A_t = -0.2\ m_0$	$\tan\beta = 50$	$\Delta_{m_0^2} = 16$
m_0^2	$(5.5\ \text{TeV})^2$	$(4.5\ \text{TeV})^2$	$(3.5\ \text{TeV})^2$
$m_{q3}^2(t_T)$	$(4376\ \text{GeV})^2$	$(3563\ \text{GeV})^2$	$(2752\ \text{GeV})^2$
$m_{u_3^c}^2(t_T)$	$(3798\ \text{GeV})^2$	$(3106\ \text{GeV})^2$	$(2413\ \text{GeV})^2$
$m_{h_u}^2(t_T)$	$(539\ \text{GeV})^2$	$(361\ \text{GeV})^2$	$-(44\ \text{GeV})^2$
$m_{h_d}^2(t_T)$	$(2053\ \text{GeV})^2$	$(1565\ \text{GeV})^2$	$(1046\ \text{GeV})^2$
Case III	$A_t = -0.5\ m_0$	$\tan\beta = 50$	$\Delta_{m_0^2} = 9$
m_0^2	$(5.5\ \text{TeV})^2$	$(4.5\ \text{TeV})^2$	$(3.5\ \text{TeV})^2$
$m_{q3}^2(t_T)$	$(4284\ \text{GeV})^2$	$(3532\ \text{GeV})^2$	$(2630\ \text{GeV})^2$
$m_{u_3^c}^2(t_T)$	$(3755\ \text{GeV})^2$	$(3088\ \text{GeV})^2$	$(2373\ \text{GeV})^2$
$m_{h_u}^2(t_T)$	$-(363\ \text{GeV})^2$	$-(41\ \text{GeV})^2$	$-(546\ \text{GeV})^2$
$m_{h_d}^2(t_T)$	$(1447\ \text{GeV})^2$	$(1359\ \text{GeV})^2$	$-(950\ \text{GeV})^2$
Case IV	$A_t = 0$	$\tan\beta = 25$	$\Delta_{m_0^2} = 57$
m_0^2	$(5.5\ \text{TeV})^2$	$(4.5\ \text{TeV})^2$	$(3.5\ \text{TeV})^2$
$m_{q3}^2(t_T)$	$(4915\ \text{GeV})^2$	$(4025\ \text{GeV})^2$	$(3134\ \text{GeV})^2$
$m_{u_3^c}^2(t_T)$	$(3770\ \text{GeV})^2$	$(3086\ \text{GeV})^2$	$(2400\ \text{GeV})^2$
$m_{h_u}^2(t_T)$	$(152\ \text{GeV})^2$	$-(220\ \text{GeV})^2$	$-(293\ \text{GeV})^2$
$m_{h_d}^2(t_T)$	$(5057\ \text{GeV})^2$	$(4136\ \text{GeV})^2$	$(3215\ \text{GeV})^2$

at
Q_T = 3.5 TeV

for various trial m_0^2 s

when $Q_M \approx 1.3\times10^{16}$ GeV

Case I	$A_t = 0$	$\tan\beta = 50$	$\boldsymbol{\Delta_{m_0^2} = 1}$
$\mathbf{m_0^2}$	$(\mathbf{5.5}\,\text{TeV})^2$	$(\mathbf{4.5}\,\text{TeV})^2$	$(\mathbf{3.5}\,\text{TeV})^2$
$m_{q3}^2(t_T)$	$(4363\,\text{GeV})^2$	$(3551\,\text{GeV})^2$	$(2744\,\text{GeV})^2$
$m_{u_3^c}^2(t_T)$	$(3789\,\text{GeV})^2$	$(3098\,\text{GeV})^2$	$(2406\,\text{GeV})^2$
$\mathbf{m_{h_u}^2(t_T)}$	$(\mathbf{431}\,\text{GeV})^2$	$(\mathbf{189}\,\text{GeV})^2$	$-(\mathbf{251}\,\text{GeV})^2$
$m_{h_d}^2(t_T)$	$(2022\,\text{GeV})^2$	$(1512\,\text{GeV})^2$	$(1008\,\text{GeV})^2$
Case II	$A_t = -0.2\,m_0$	$\tan\beta = 50$	$\boldsymbol{\Delta_{m_0^2} = 16}$
$\mathbf{m_0^2}$	$(\mathbf{5.5}\,\text{TeV})^2$	$(\mathbf{4.5}\,\text{TeV})^2$	$(\mathbf{3.5}\,\text{TeV})^2$
$m_{q3}^2(t_T)$	$(4376\,\text{GeV})^2$	$(3563\,\text{GeV})^2$	$(2752\,\text{GeV})^2$
$m_{u_3^c}^2(t_T)$	$(3798\,\text{GeV})^2$	$(3106\,\text{GeV})^2$	$(2413\,\text{GeV})^2$
$\mathbf{m_{h_u}^2(t_T)}$	$(\mathbf{539}\,\text{GeV})^2$	$(\mathbf{361}\,\text{GeV})^2$	$-(\mathbf{44}\,\text{GeV})^2$
$m_{h_d}^2(t_T)$	$(2053\,\text{GeV})^2$	$(1565\,\text{GeV})^2$	$(1046\,\text{GeV})^2$
Case III	$A_t = -0.5\,m_0$	$\tan\beta = 50$	$\boldsymbol{\Delta_{m_0^2} = 9}$
$\mathbf{m_0^2}$	$(\mathbf{5.5}\,\text{TeV})^2$	$(\mathbf{4.5}\,\text{TeV})^2$	$(\mathbf{3.5}\,\text{TeV})^2$
$m_{q3}^2(t_T)$	$(4284\,\text{GeV})^2$	$(3532\,\text{GeV})^2$	$(2630\,\text{GeV})^2$
$m_{u_3^c}^2(t_T)$	$(3755\,\text{GeV})^2$	$(3088\,\text{GeV})^2$	$(2373\,\text{GeV})^2$
$\mathbf{m_{h_u}^2(t_T)}$	$-(\mathbf{363}\,\text{GeV})^2$	$-(\mathbf{41}\,\text{GeV})^2$	$-(\mathbf{546}\,\text{GeV})^2$
$m_{h_d}^2(t_T)$	$(1447\,\text{GeV})^2$	$(1359\,\text{GeV})^2$	$-(950\,\text{GeV})^2$
Case IV	$A_t = 0$	$\tan\beta = 25$	$\boldsymbol{\Delta_{m_0^2} = 57}$
$\mathbf{m_0^2}$	$(\mathbf{5.5}\,\text{TeV})^2$	$(\mathbf{4.5}\,\text{TeV})^2$	$(\mathbf{3.5}\,\text{TeV})^2$
$m_{q3}^2(t_T)$	$(4915\,\text{GeV})^2$	$(4025\,\text{GeV})^2$	$(3134\,\text{GeV})^2$
$m_{u_3^c}^2(t_T)$	$(3770\,\text{GeV})^2$	$(3086\,\text{GeV})^2$	$(2400\,\text{GeV})^2$
$\mathbf{m_{h_u}^2(t_T)}$	$(\mathbf{152}\,\text{GeV})^2$	$-(\mathbf{220}\,\text{GeV})^2$	$-(\mathbf{293}\,\text{GeV})^2$
$m_{h_d}^2(t_T)$	$(5057\,\text{GeV})^2$	$(4136\,\text{GeV})^2$	$(3215\,\text{GeV})^2$

at

Q_T = 3.5 TeV

for various trial m_0^2 s

when $Q_M \approx 1.3 \times 10^{16}$ GeV

Case I	$A_t = 0$	$\tan\beta = 50$	$\Delta_{m_0^2} = 1$
m_0^2	$(5.5\ \text{TeV})^2$	$(4.5\ \text{TeV})^2$	$(3.5\ \text{TeV})^2$
$m_{q3}^2(t_T)$	$(4363\ \text{GeV})^2$	$(3551\ \text{GeV})^2$	$(2744\ \text{GeV})^2$
$m_{u_3^c}^2(t_T)$	$(3789\ \text{GeV})^2$	$(3098\ \text{GeV})^2$	$(2406\ \text{GeV})^2$
$m_{h_u}^2(t_T)$	$(431\ \text{GeV})^2$	$(189\ \text{GeV})^2$	$-(251\ \text{GeV})^2$
$m_{h_d}^2(t_T)$	$(2022\ \text{GeV})^2$	$(1512\ \text{GeV})^2$	$(1008\ \text{GeV})^2$
Case II	$A_t = -0.2\ m_0$	$\tan\beta = 50$	$\Delta_{m_0^2} = 16$
m_0^2	$(5.5\ \text{TeV})^2$	$(4.5\ \text{TeV})^2$	$(3.5\ \text{TeV})^2$
$m_{q3}^2(t_T)$	$(4376\ \text{GeV})^2$	$(3563\ \text{GeV})^2$	$(2752\ \text{GeV})^2$
$m_{u_3^c}^2(t_T)$	$(3798\ \text{GeV})^2$	$(3106\ \text{GeV})^2$	$(2413\ \text{GeV})^2$
$m_{h_u}^2(t_T)$	$(539\ \text{GeV})^2$	$(361\ \text{GeV})^2$	$-(44\ \text{GeV})^2$
$m_{h_d}^2(t_T)$	$(2053\ \text{GeV})^2$	$(1565\ \text{GeV})^2$	$(1046\ \text{GeV})^2$
Case III	$A_t = -0.5\ m_0$	$\tan\beta = 50$	$\Delta_{m_0^2} = 9$
m_0^2	$(5.5\ \text{TeV})^2$	$(4.5\ \text{TeV})^2$	$(3.5\ \text{TeV})^2$
$m_{q3}^2(t_T)$	$(4284\ \text{GeV})^2$	$(3532\ \text{GeV})^2$	$(2630\ \text{GeV})^2$
$m_{u_3^c}^2(t_T)$	$(3755\ \text{GeV})^2$	$(3088\ \text{GeV})^2$	$(2373\ \text{GeV})^2$
$m_{h_u}^2(t_T)$	$-(363\ \text{GeV})^2$	$-(41\ \text{GeV})^2$	$-(546\ \text{GeV})^2$
$m_{h_d}^2(t_T)$	$(1447\ \text{GeV})^2$	$(1359\ \text{GeV})^2$	$-(950\ \text{GeV})^2$
Case IV	$A_t = 0$	$\tan\beta = 25$	$\Delta_{m_0^2} = 57$
m_0^2	$(5.5\ \text{TeV})^2$	$(4.5\ \text{TeV})^2$	$(3.5\ \text{TeV})^2$
$m_{q3}^2(t_T)$	$(4915\ \text{GeV})^2$	$(4025\ \text{GeV})^2$	$(3134\ \text{GeV})^2$
$m_{u_3^c}^2(t_T)$	$(3770\ \text{GeV})^2$	$(3086\ \text{GeV})^2$	$(2400\ \text{GeV})^2$
$m_{h_u}^2(t_T)$	$(152\ \text{GeV})^2$	$-(220\ \text{GeV})^2$	$-(293\ \text{GeV})^2$
$m_{h_d}^2(t_T)$	$(5057\ \text{GeV})^2$	$(4136\ \text{GeV})^2$	$(3215\ \text{GeV})^2$

at
Q_T = 3.5 TeV

for various trial m_0^2 s

when $Q_M \approx 1.3 \times 10^{16}$ GeV

Case I	$A_t = 0$	$\tan\beta = 50$	$\Delta_{m_0^2} = 1$
m_0^2	$(5.5\ \text{TeV})^2$	$(4.5\ \text{TeV})^2$	$(3.5\ \text{TeV})^2$
$m_{q_3}^2(t_T)$	$(4363\ \text{GeV})^2$	$(3551\ \text{GeV})^2$	$(2744\ \text{GeV})^2$
$m_{u_3^c}^2(t_T)$	$(3789\ \text{GeV})^2$	$(3098\ \text{GeV})^2$	$(2406\ \text{GeV})^2$
$m_{h_u}^2(t_T)$	$(431\ \text{GeV})^2$	$(189\ \text{GeV})^2$	$-(251\ \text{GeV})^2$
$m_{h_d}^2(t_T)$	$(2022\ \text{GeV})^2$	$(1512\ \text{GeV})^2$	$(1008\ \text{GeV})^2$

Case II	$A_t = -0.2\ m_0$	$\tan\beta = 50$	$\Delta_{m_0^2} = 16$
m_0^2	$(5.5\ \text{TeV})^2$	$(4.5\ \text{TeV})^2$	$(3.5\ \text{TeV})^2$
$m_{q_3}^2(t_T)$	$(4376\ \text{GeV})^2$	$(3563\ \text{GeV})^2$	$(2752\ \text{GeV})^2$
$m_{u_3^c}^2(t_T)$	$(3798\ \text{GeV})^2$	$(3106\ \text{GeV})^2$	$(2413\ \text{GeV})^2$
$m_{h_u}^2(t_T)$	$(539\ \text{GeV})^2$	$(361\ \text{GeV})^2$	$-(44\ \text{GeV})^2$
$m_{h_d}^2(t_T)$	$(2053\ \text{GeV})^2$	$(1565\ \text{GeV})^2$	$(1046\ \text{GeV})^2$

Case III	$A_t = -0.5\ m_0$	$\tan\beta = 50$	$\Delta_{m_0^2} = 9$
m_0^2	$(5.5\ \text{TeV})^2$	$(4.5\ \text{TeV})^2$	$(3.5\ \text{TeV})^2$
$m_{q_3}^2(t_T)$	$(4284\ \text{GeV})^2$	$(3532\ \text{GeV})^2$	$(2630\ \text{GeV})^2$
$m_{u_3^c}^2(t_T)$	$(3755\ \text{GeV})^2$	$(3088\ \text{GeV})^2$	$(2373\ \text{GeV})^2$
$m_{h_u}^2(t_T)$	$-(363\ \text{GeV})^2$	$-(41\ \text{GeV})^2$	$-(546\ \text{GeV})^2$
$m_{h_d}^2(t_T)$	$(1447\ \text{GeV})^2$	$(1359\ \text{GeV})^2$	$-(950\ \text{GeV})^2$

Case IV	$A_t = 0$	$\tan\beta = 25$	$\Delta_{m_0^2} = 57$
m_0^2	$(5.5\ \text{TeV})^2$	$(4.5\ \text{TeV})^2$	$(3.5\ \text{TeV})^2$
$m_{q_3}^2(t_T)$	$(4915\ \text{GeV})^2$	$(4025\ \text{GeV})^2$	$(3134\ \text{GeV})^2$
$m_{u_3^c}^2(t_T)$	$(3770\ \text{GeV})^2$	$(3086\ \text{GeV})^2$	$(2400\ \text{GeV})^2$
$m_{h_u}^2(t_T)$	$(152\ \text{GeV})^2$	$-(220\ \text{GeV})^2$	$-(293\ \text{GeV})^2$
$m_{h_d}^2(t_T)$	$(5057\ \text{GeV})^2$	$(4136\ \text{GeV})^2$	$(3215\ \text{GeV})^2$

at

Q_T = 3.5 TeV

for various trial m_0^2 s

when $Q_M \approx$ 1.3×10^{16} GeV

Case I	$A_t = 0$	$\tan\beta = 50$	$\Delta_{m_0^2} = 1$
$\mathbf{m_0^2}$	$(5.5\ \text{TeV})^2$	$(4.5\ \text{TeV})^2$	$(3.5\ \text{TeV})^2$
$m_{q_3}^2(t_T)$	$(4363\ \text{GeV})^2$	$(3551\ \text{GeV})^2$	$(2744\ \text{GeV})^2$
$m_{u_3^c}^2(t_T)$	$(3789\ \text{GeV})^2$	$(3098\ \text{GeV})^2$	$(2406\ \text{GeV})^2$
$\mathbf{m_{h_u}^2(t_T)}$	$(\mathbf{431}\ \text{GeV})^2$	$(\mathbf{189}\ \text{GeV})^2$	$-(\mathbf{251}\ \text{GeV})^2$
$m_{h_d}^2(t_T)$	$(2022\ \text{GeV})^2$	$(1512\ \text{GeV})^2$	$(1008\ \text{GeV})^2$
Case II	$A_t = -0.2\ m_0$	$\tan\beta = 50$	$\Delta_{m_0^2} = 16$
$\mathbf{m_0^2}$	$(5.5\ \text{TeV})^2$	$(4.5\ \text{TeV})^2$	$(3.5\ \text{TeV})^2$
$m_{q_3}^2(t_T)$	$(4376\ \text{GeV})^2$	$(3563\ \text{GeV})^2$	$(2752\ \text{GeV})^2$
$m_{u_3^c}^2(t_T)$	$(3798\ \text{GeV})^2$	$(3106\ \text{GeV})^2$	$(2413\ \text{GeV})^2$
$\mathbf{m_{h_u}^2(t_T)}$	$(\mathbf{539}\ \text{GeV})^2$	$(\mathbf{361}\ \text{GeV})^2$	$-(\mathbf{44}\ \text{GeV})^2$
$m_{h_d}^2(t_T)$	$(2053\ \text{GeV})^2$	$(1565\ \text{GeV})^2$	$(1046\ \text{GeV})^2$
Case III	$A_t = -0.5\ m_0$	$\tan\beta = 50$	$\Delta_{m_0^2} = 9$
$\mathbf{m_0^2}$	$(5.5\ \text{TeV})^2$	$(4.5\ \text{TeV})^2$	$(3.5\ \text{TeV})^2$
$m_{q_3}^2(t_T)$	$(4284\ \text{GeV})^2$	$(3532\ \text{GeV})^2$	$(2630\ \text{GeV})^2$
$m_{u_3^c}^2(t_T)$	$(3755\ \text{GeV})^2$	$(3088\ \text{GeV})^2$	$(2373\ \text{GeV})^2$
$\mathbf{m_{h_u}^2(t_T)}$	$-(\mathbf{363}\ \text{GeV})^2$	$-(\mathbf{41}\ \text{GeV})^2$	$-(\mathbf{546}\ \text{GeV})^2$
$m_{h_d}^2(t_T)$	$(1447\ \text{GeV})^2$	$(1359\ \text{GeV})^2$	$-(950\ \text{GeV})^2$
Case IV	$A_t = 0$	$\tan\beta = 25$	$\Delta_{m_0^2} = 57$
$\mathbf{m_0^2}$	$(5.5\ \text{TeV})^2$	$(4.5\ \text{TeV})^2$	$(3.5\ \text{TeV})^2$
$m_{q_3}^2(t_T)$	$(4915\ \text{GeV})^2$	$(4025\ \text{GeV})^2$	$(3134\ \text{GeV})^2$
$m_{u_3^c}^2(t_T)$	$(3770\ \text{GeV})^2$	$(3086\ \text{GeV})^2$	$(2400\ \text{GeV})^2$
$\mathbf{m_{h_u}^2(t_T)}$	$(\mathbf{152}\ \text{GeV})^2$	$-(\mathbf{220}\ \text{GeV})^2$	$-(\mathbf{293}\ \text{GeV})^2$
$m_{h_d}^2(t_T)$	$(5057\ \text{GeV})^2$	$(4136\ \text{GeV})^2$	$(3215\ \text{GeV})^2$

at
Q_T = 3.5 TeV

for various trial m_0^2 s

when $Q_M \approx 1.3\times10^{16}$ GeV

Case I	$A_t = 0$	$\tan\beta = 50$	$\Delta_{m_0^2} = 1$
m_0^2	$(5.5\ \text{TeV})^2$	$(4.5\ \text{TeV})^2$	$(3.5\ \text{TeV})^2$
$m_{q3}^2(t_T)$	$(4363\ \text{GeV})^2$	$(3551\ \text{GeV})^2$	$(2744\ \text{GeV})^2$
$m_{u_3^c}^2(t_T)$	$(3789\ \text{GeV})^2$	$(3098\ \text{GeV})^2$	$(2406\ \text{GeV})^2$
$m_{h_u}^2(t_T)$	$(431\ \text{GeV})^2$	$(189\ \text{GeV})^2$	$-(251\ \text{GeV})^2$
$m_{h_d}^2(t_T)$	$(2022\ \text{GeV})^2$	$(1512\ \text{GeV})^2$	$(1008\ \text{GeV})^2$
Case II	$A_t = -0.2\ m_0$	$\tan\beta = 50$	$\Delta_{m_0^2} = 16$
m_0^2	$(5.5\ \text{TeV})^2$	$(4.5\ \text{TeV})^2$	$(3.5\ \text{TeV})^2$
$m_{q3}^2(t_T)$	$(4376\ \text{GeV})^2$	$(3563\ \text{GeV})^2$	$(2752\ \text{GeV})^2$
$m_{u_3^c}^2(t_T)$	$(3798\ \text{GeV})^2$	$(3106\ \text{GeV})^2$	$(2413\ \text{GeV})^2$
$m_{h_u}^2(t_T)$	$(539\ \text{GeV})^2$	$(361\ \text{GeV})^2$	$-(44\ \text{GeV})^2$
$m_{h_d}^2(t_T)$	$(2053\ \text{GeV})^2$	$(1565\ \text{GeV})^2$	$(1046\ \text{GeV})^2$
Case III	$A_t = -0.5\ m_0$	$\tan\beta = 50$	$\Delta_{m_0^2} = 9$
[illegible]	[illegible]	...V)^2	$(3.5\ \text{TeV})^2$
[illegible]	[illegible]	[illegible]	$(2630\ \text{GeV})^2$
[illegible]	[illegible]	[illegible]	...373 GeV)^2
[illegible]	[illegible]	[illegible]	...46 GeV)^2
[illegible]	[illegible]	[illegible]	...50 GeV)^2
[illegible]	[illegible]	[illegible]	$\Delta_{m_0^2} = 57$
[illegible]	[illegible]	[illegible]	$(3.5\ \text{TeV})^2$
$m_{q3}^2(t_T)$	[illegible]	...025 GeV)^2	$(3134\ \text{GeV})^2$
$m_{u_3^c}^2(t_T)$	$(3770\ \text{GeV})^2$	$(3086\ \text{GeV})^2$	$(2400\ \text{GeV})^2$
$m_{h_u}^2(t_T)$	$(152\ \text{GeV})^2$	$-(220\ \text{GeV})^2$	$-(293\ \text{GeV})^2$
$m_{h_d}^2(t_T)$	$(5057\ \text{GeV})^2$	$(4136\ \text{GeV})^2$	$(3215\ \text{GeV})^2$

For Case I, II, III, IV,

$\Delta_{At} \approx \{0, 10, 118, 0\}$

$|\mu|$/GeV $\approx \{480, 390, 510, 580\}$

at
Q_T = 3.5 TeV

for various trial m_0^2 s

when $Q_M \approx 1.3 \times 10^{16}$ GeV

Case I	$A_t = 0$	$\tan\beta = 50$	$\boldsymbol{\Delta_{m_0^2} = 1}$
$\mathbf{m_0^2}$	$\mathbf{(5.5}$ TeV$)^2$	$\mathbf{(4.5}$ TeV$)^2$	$\mathbf{(3.5}$ TeV$)^2$
$m_{q_3}^2(t_T)$	$(4363\ \text{GeV})^2$	$(3551\ \text{GeV})^2$	$(2744\ \text{GeV})^2$
$m_{u_3^c}^2(t_T)$	$(3789\ \text{GeV})^2$	$(3098\ \text{GeV})^2$	$(2406\ \text{GeV})^2$
$\mathbf{m_{h_u}^2(t_T)}$	$(\mathbf{431}\ \text{GeV})^2$	$(\mathbf{189}\ \text{GeV})^2$	$-(\mathbf{251}\ \text{GeV})^2$
$m_{h_d}^2(t_T)$	$(2022\ \text{GeV})^2$	$(1512\ \text{GeV})^2$	$(1008\ \text{GeV})^2$
Case II	$A_t = -0.2\ m_0$	$\tan\beta = 50$	$\boldsymbol{\Delta_{m_0^2} = 16}$
$\mathbf{m_0^2}$	$\mathbf{(5.5}$ TeV$)^2$	$\mathbf{(4.5}$ TeV$)^2$	$\mathbf{(3.5}$ TeV$)^2$
$m_{q_3}^2(t_T)$	$(4376\ \text{GeV})^2$	$(3563\ \text{GeV})^2$	$(2752\ \text{GeV})^2$
$m_{u_3^c}^2(t_T)$	$(3798\ \text{GeV})^2$	$(3106\ \text{GeV})^2$	$(2413\ \text{GeV})^2$
$\mathbf{m_{h_u}^2(t_T)}$	$(\mathbf{539}\ \text{GeV})^2$	$(\mathbf{361}\ \text{GeV})^2$	$-(\mathbf{44}\ \text{GeV})^2$
$m_{h_d}^2(t_T)$	$(2053\ \text{GeV})^2$	$(1565\ \text{GeV})^2$	$(1046\ \text{GeV})^2$
Case III	$A_t = -0.5\ m_0$	$\tan\beta = 50$	$\boldsymbol{\Delta_{m_0^2} = 9}$
		...V$)^2$	$\mathbf{(3.5}$ TeV$)^2$
			$(2630\ \text{GeV})^2$
			...373 GeV$)^2$
			...46 GeV$)^2$
			...50 GeV$)^2$
			$\boldsymbol{\Delta_{m_0^2} = 57}$
			$\mathbf{(3.5}$ TeV$)^2$
$m_{q_3}^2$...		...025 GeV$)^2$	$(3134\ \text{GeV})^2$
$m_{u_3^c}^2(t_T)$	$(3770\ \text{GeV})^2$	$(3086\ \text{GeV})^2$	$(2400\ \text{GeV})^2$
$\mathbf{m_{h_u}^2(t_T)}$	$(\mathbf{152}\ \text{GeV})^2$	$-(\mathbf{220}\ \text{GeV})^2$	$-(\mathbf{293}\ \text{GeV})^2$
$m_{h_d}^2(t_T)$	$(5057\ \text{GeV})^2$	$(4136\ \text{GeV})^2$	$(3215\ \text{GeV})^2$

For A_t/m_0 = +0.1,

$\{\Delta_{m02}, \Delta_{At}, |\mu|/\text{GeV}\} \approx \{22, 33, 570\}$

SUSY particle masses

For $m_0^2 \approx (4.5\,\mathrm{TeV})^2$, $\tan\beta \gtrsim 25$, and

$-0.5 < A_t/m_0 \lesssim +0.1$,

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 $m_0^2 \approx (4.5\,\mathrm{TeV})^2$,

$-0.5 < A_t/m_0 \lesssim +0.1$,

Even for

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

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 $m_0^2 \approx (4.5\,\mathrm{TeV})^2$, $\tan\beta \gtrsim 25$, and

$-0.5 < A_t/m_0 \lesssim +0.1$,

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

$$M_a(t_T) \approx 0.36 \times m_0 \times g_a^2(t_T)$$

SUSY particle masses

For $m_0^2 \approx (4.5\,\mathrm{TeV})^2$, $\tan\beta \gtrsim 25$, and

$$-0.5 \;<\; A_t/m_0 \;\lesssim\; +0.1$$,

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

$$M_{3,2,1} \approx \{\underline{1.7\,\mathrm{TeV},}\;\; 660\,\mathrm{GeV},\;\; 360\,\mathrm{GeV}\}$$

PREDICTIONS !

testable at LHC run2

SUSY particle masses

For $m_0^2 \approx (4.5\,\mathrm{TeV})^2$, $\tan\beta \gtrsim 25$, and

$$-0.5 < A_t/m_0 \lesssim +0.1$$,

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

$$M_{3,2,1} \approx \{\underline{1.7\,\mathrm{TeV},}\ \ 660\,\mathrm{GeV},\ \ 360\,\mathrm{GeV}\}$$

sleptons , sbottom masses > 3 – 4 TeV

SUSY particle masses

For $m_0^2 \approx (4.5\,\mathrm{TeV})^2$, $\tan\beta \gtrsim 25$, and

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

$$M_{3,2,1} \approx \{\underline{1.7\,\mathrm{TeV},}\ \ 660\,\mathrm{GeV},\ \ 360\,\mathrm{GeV}\}$$

|μ| = 390 GeV – 590 GeV for m_Z = 91 GeV

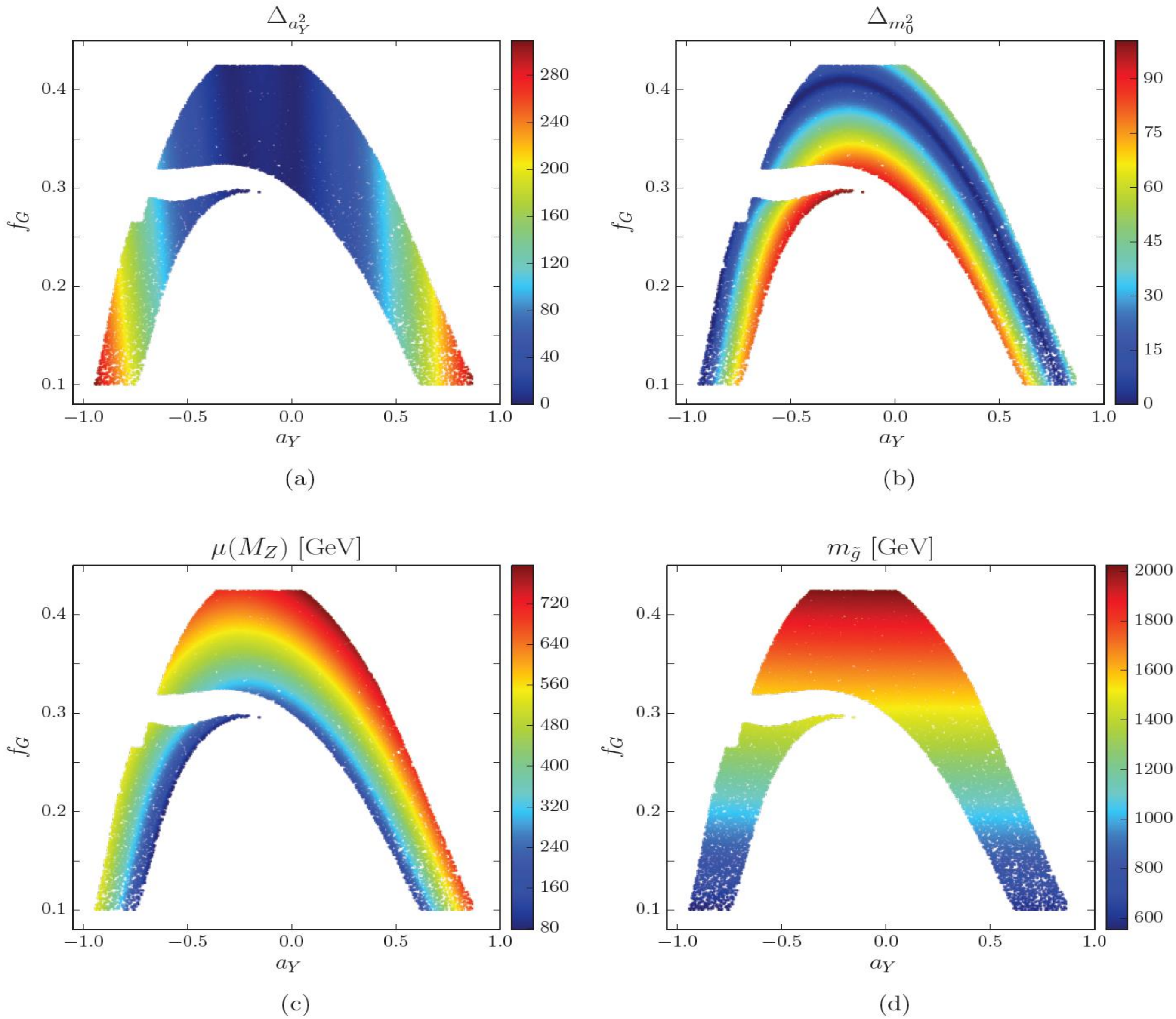
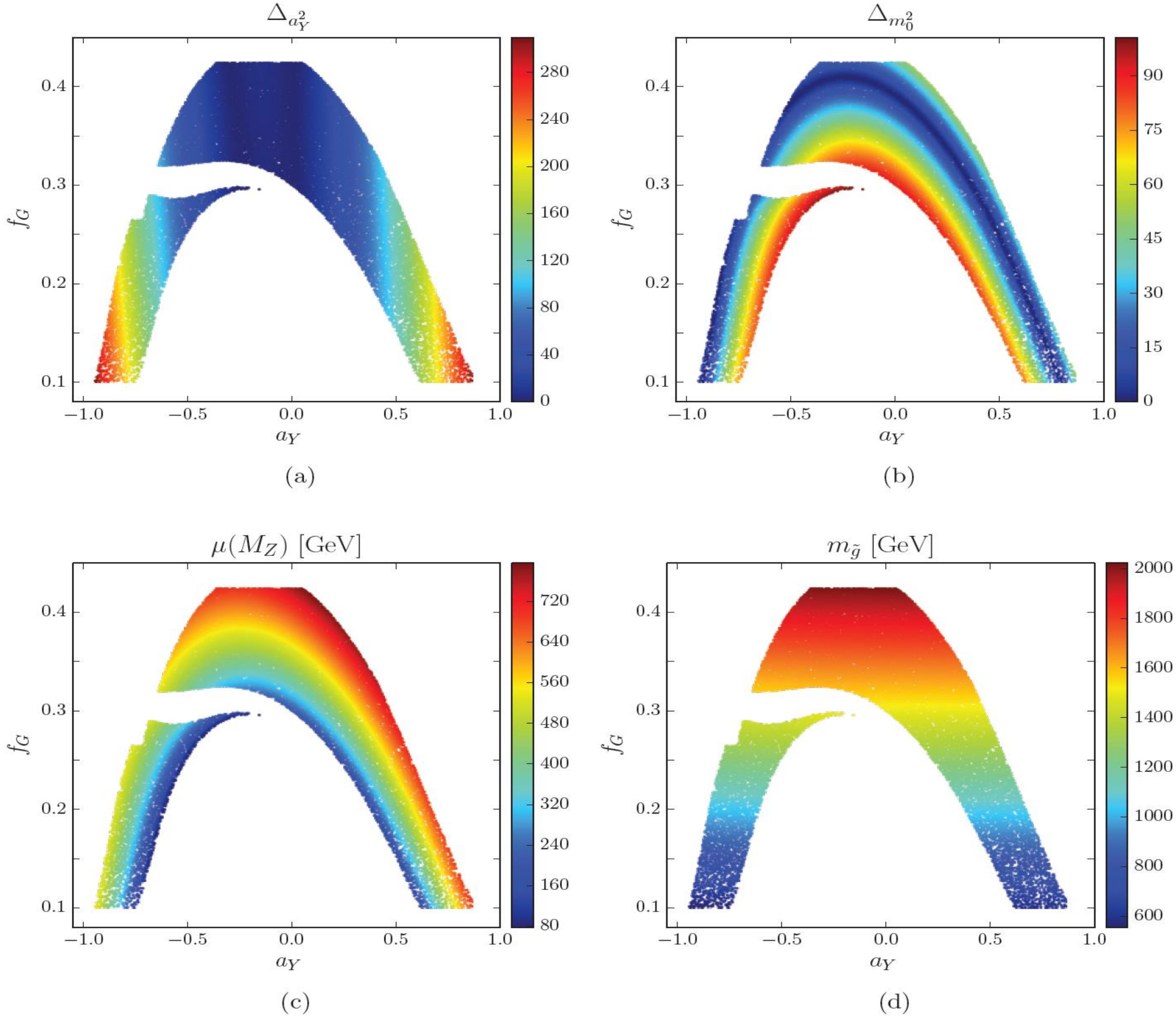


FIG. 4: Scatter plots for **(a)** $\Delta_{a_Y^2}$, **(b)** $\Delta_{m_0^2}$, and **(c)** $|\mu|$ at the M_Z scale, and **(d)** on-shell gluino mass when $m_0^2 = (4\ \text{TeV})^2$ and $\tan\beta = 50$. Here we set $M_G = 1.7 \times 10^{16}$ GeV. The stop mass scale is about 3.0 TeV.



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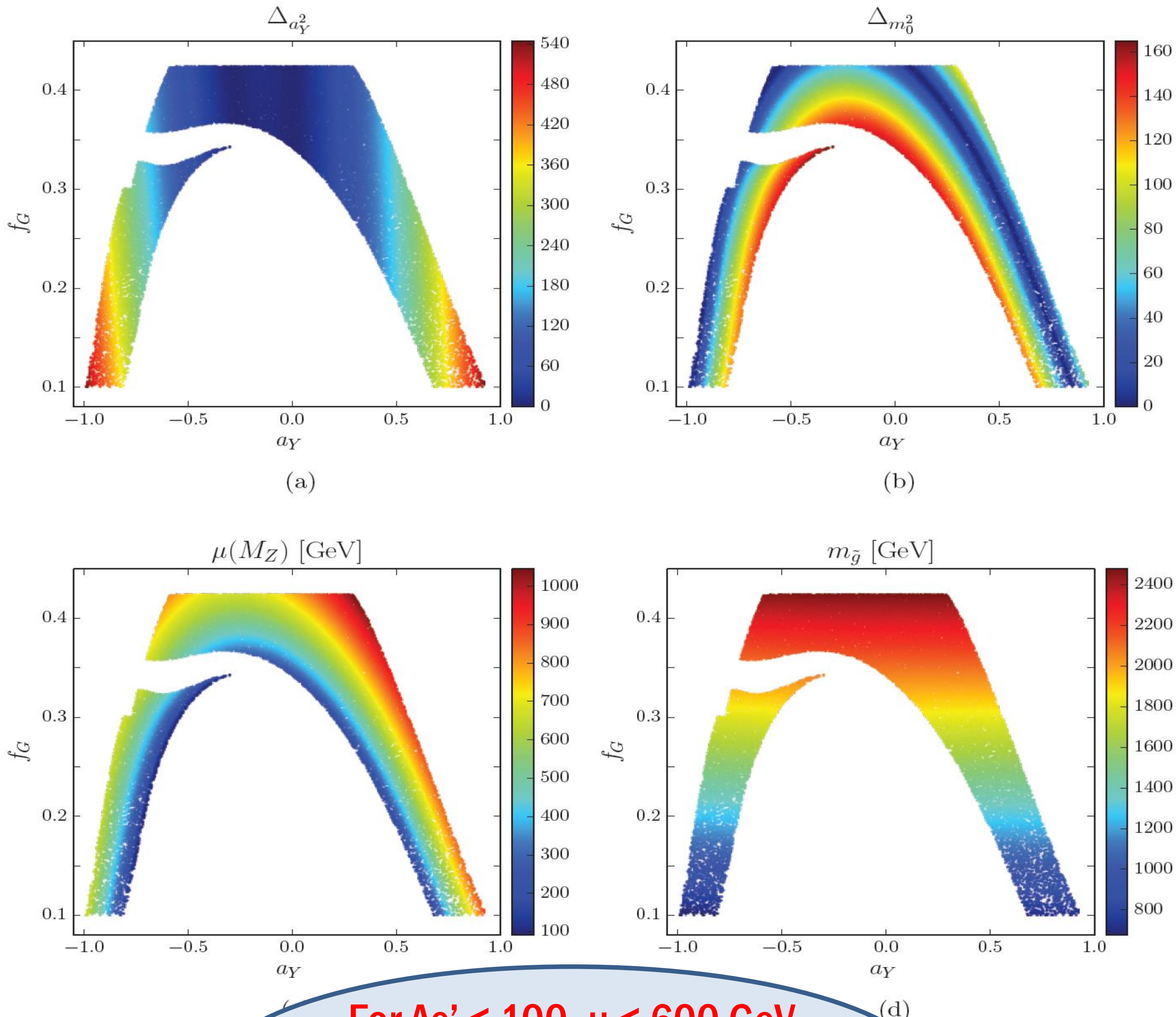
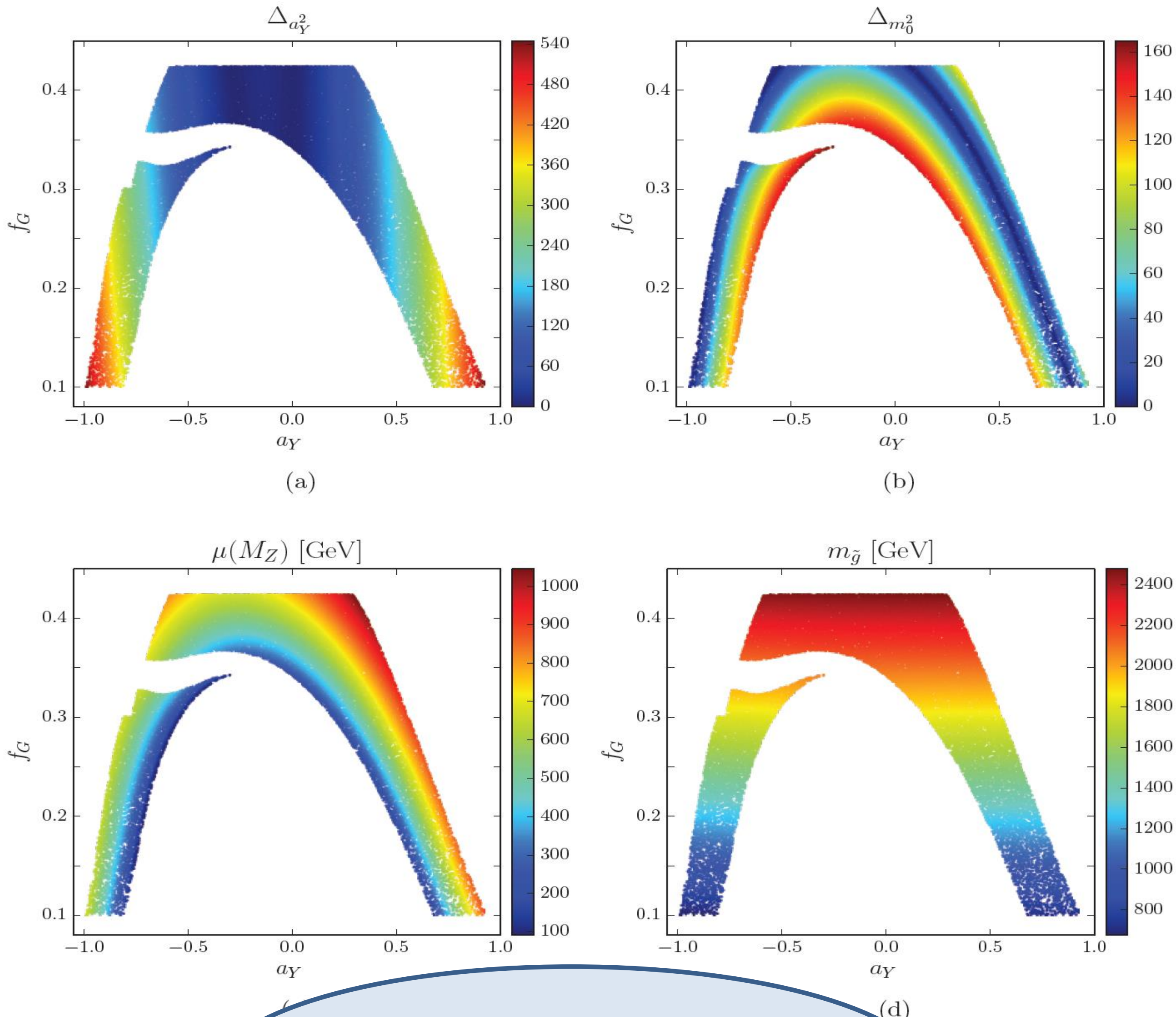


FIG. 5: Scatter … le, and **(d)** on-shell gluino mass whe… .7 × 10^{16} GeV. The

For Δs' < 100, μ < 600 GeV

0.3 < f_G < 0.4



For Δs' < 100, μ < 600 GeV

1.6 TeV < M_3 < 2,2 TeV

FIG. 5: Scatter … le, and **(d)** on-shell gluino mass whe… .7 × 10^{16} GeV. The

Conclusion

- **minimal Gravity medi. + minimal Gauge medi.**

  at the GUT scale

  = 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 ≈ $(4.5\ \text{TeV})^2$, *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.
  → 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
  1.6 TeV – 2.2 TeV.
  → It could readily tested at LHC run2.