

Relaxation of the Electro-Weak Fine-Tuning

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1. **arXiv: 1502.02311**

2. **arXiv: 1507.07611**

collaborated with **Doyoun Kim (CTPU)**

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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 obvious 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 **> 1.7 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 125 GeV Higgs mass** (without a large stop mixing).

[Feng, etal. PRL (2013)]

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

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

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

- 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 125 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 $m_{h_u}^2$ 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 : $m_{q3}^2 = m_{u3}^2 = m_{hu}^2 = \dots \equiv m_0^2$

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

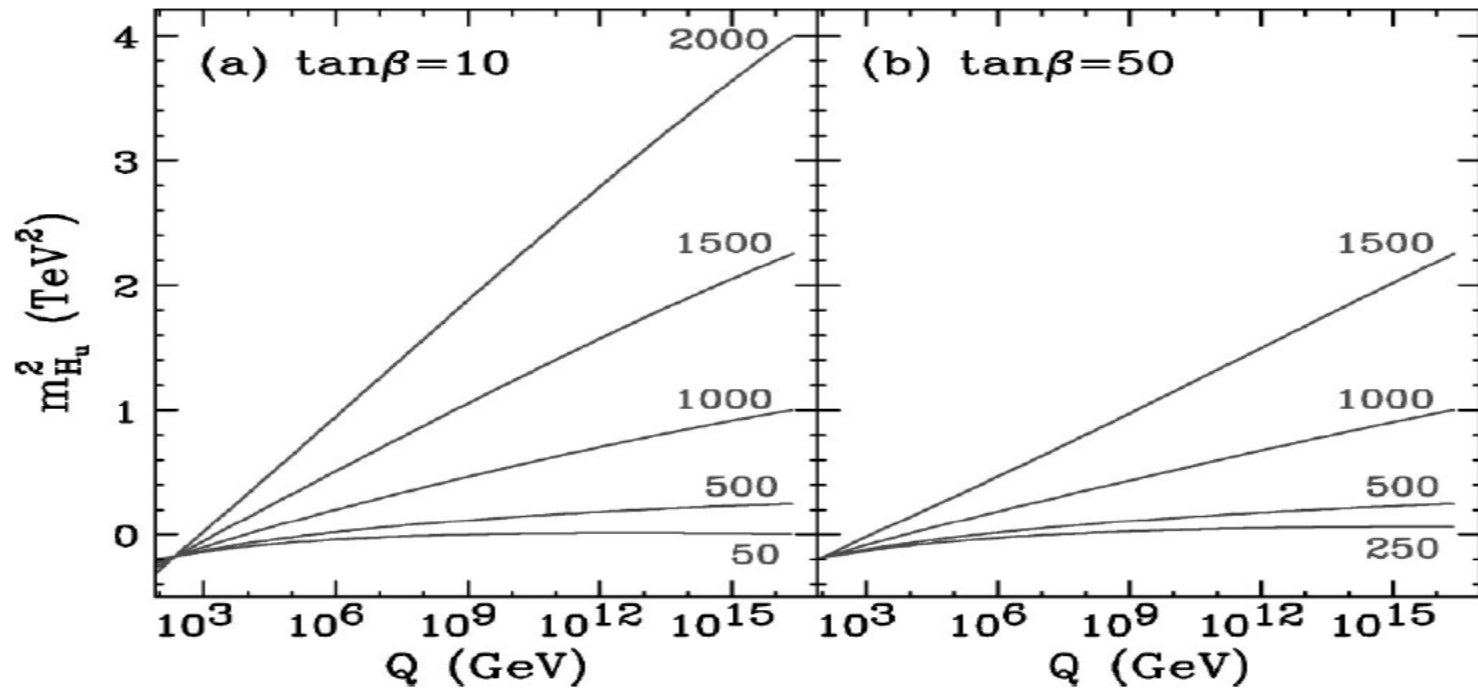
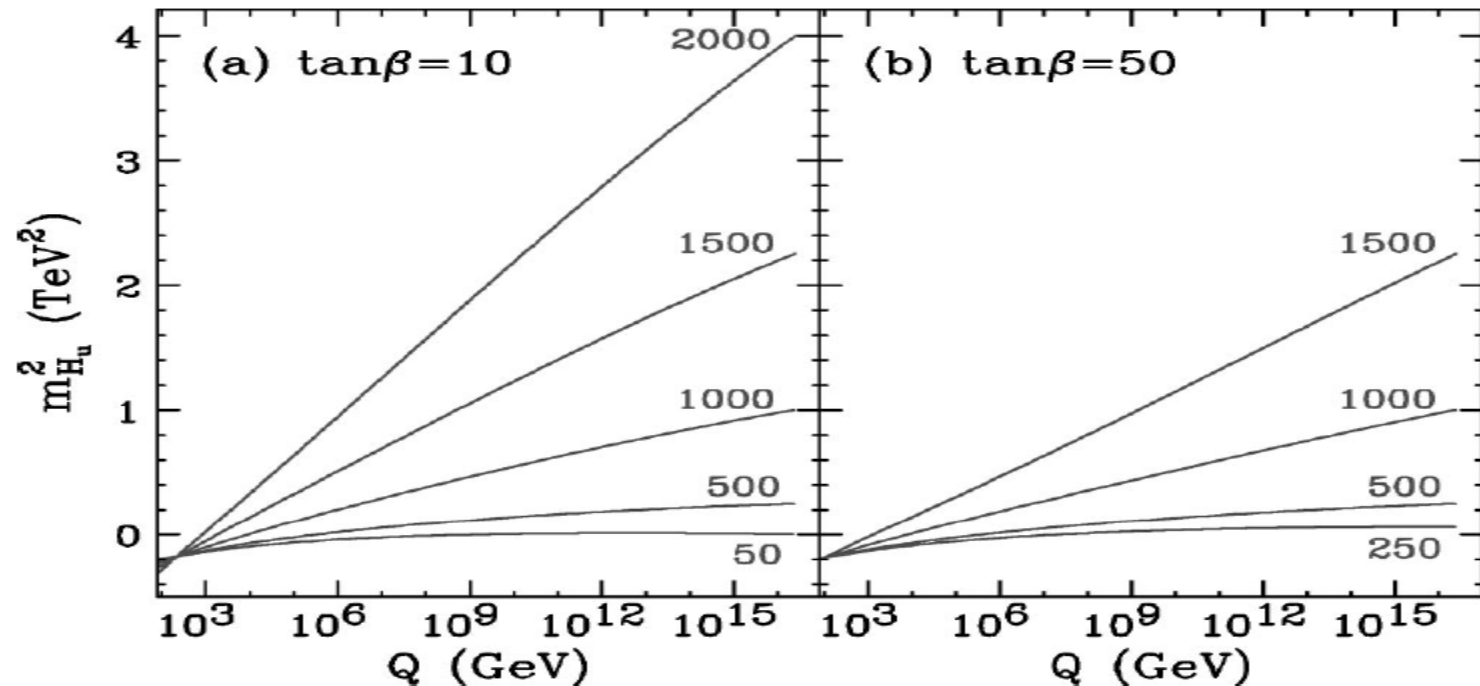


FIG. 1. The RG evolution of $m_{H_u}^2$ for (a) $\tan\beta = 10$ and (b) $\tan\beta = 50$, several values of m_0 (shown, in GeV), $M_{1/2} = 300$ GeV, $A_0 = 0$, and $m_t = 174$ GeV. For both values of $\tan\beta$, $m_{H_u}^2$ exhibits an RG focus point near the weak scale, where $Q_F^{(H_u)} \sim \mathcal{O}(100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

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 $M_3 > 1.7 \text{ TeV}$.
 $m_{1/2}$ should **NOT be small** any longer.
 $\rightarrow m_{\text{hu}}^2 < - (1 \text{ TeV})^2$
2. The **stop mass** bound has exceeded **700 GeV**.
If stop masses $> 1 \text{ TeV}$, then ???

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 $M_3 > 1.7 \text{ TeV}$,

$C_s, C_g (> 0)$

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

Challenges from experiments

In the Minimal **Gravity** Mediation,

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

$$C_s, C_g (> 0)$$

Since $M_3 > 1.4 \text{ TeV}$,

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

μ should be
LARGE $\rightarrow$ **Fine-tuning**
if stop mass $< 1 \text{ TeV}$

Challenges

from theory

1. **3-4 TeV stop masses** are necessary for **125 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 theory

In the Minimal **Gravity** Mediation,

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

For **stop mass = 3-4 TeV**,

$C_s, C_g (> 0)$

C_s becomes
sizable.

Challenges from theory

In the Minimal **Gravity** Mediation,

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

For **stop mass = 3-4 TeV**,

$C_s, C_g (> 0)$

C_s becomes
sizable.

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

Challenges from theory

In the Minimal **Gravity** Mediation,

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

For **stop mass = 3-4 TeV**,

$C_s, C_g (> 0)$

C_s becomes
sizable.

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

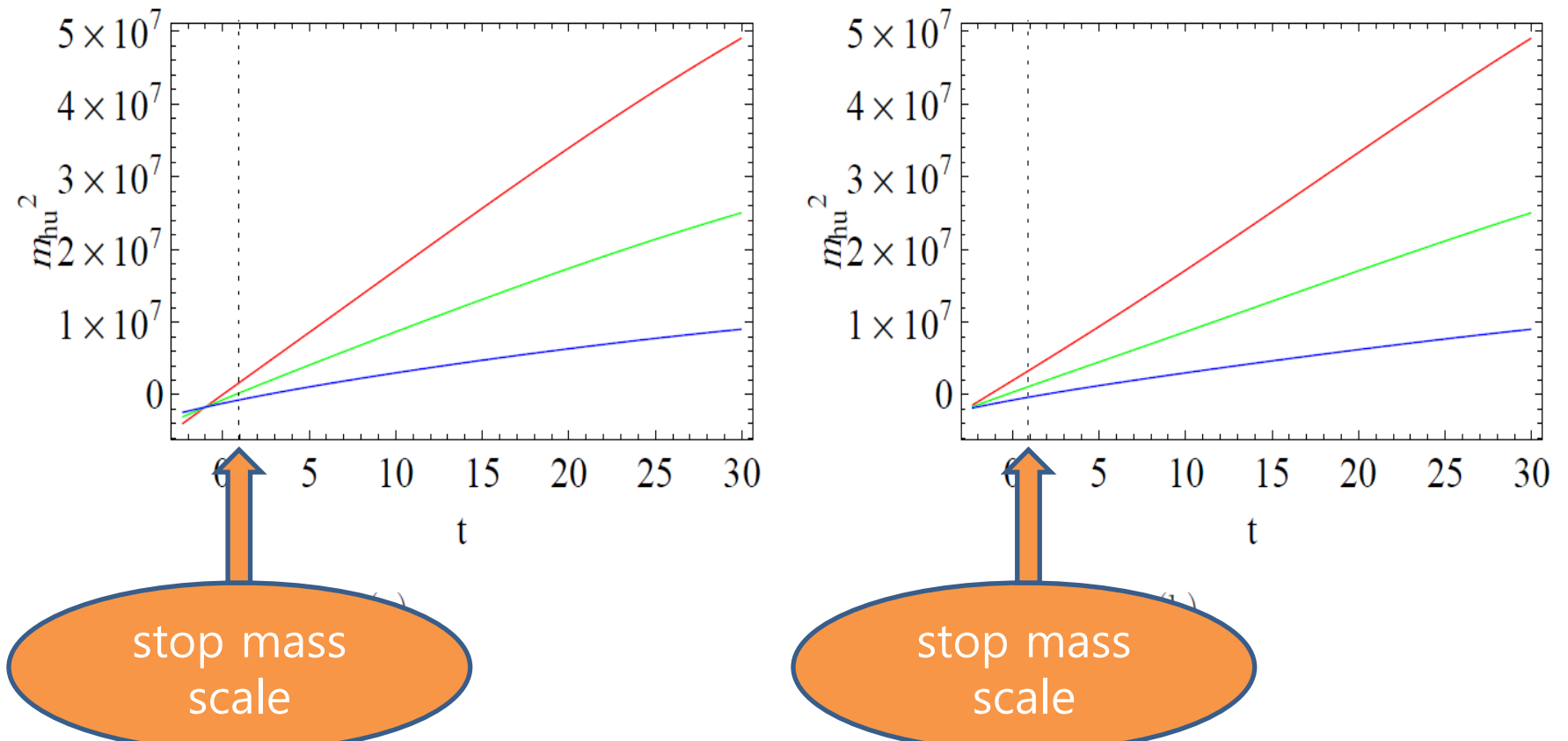
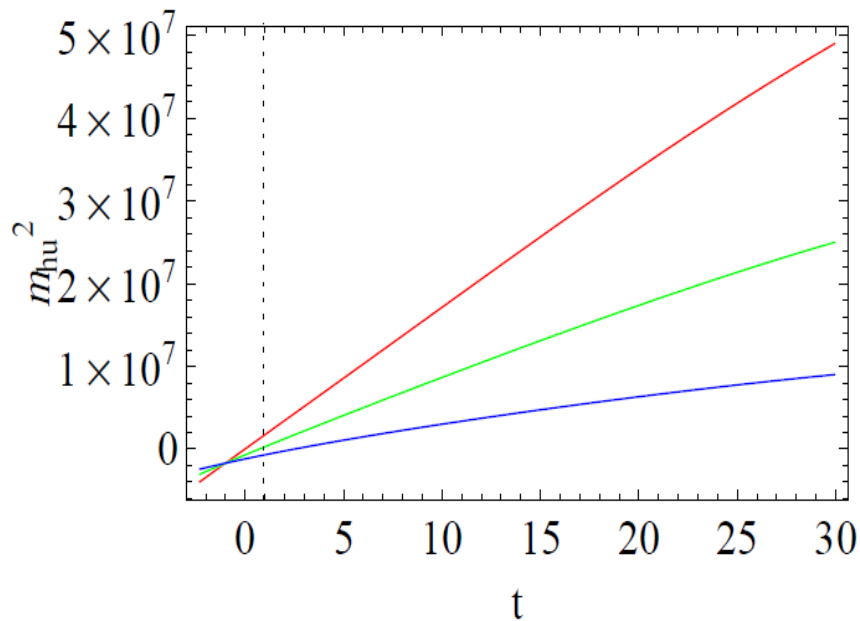
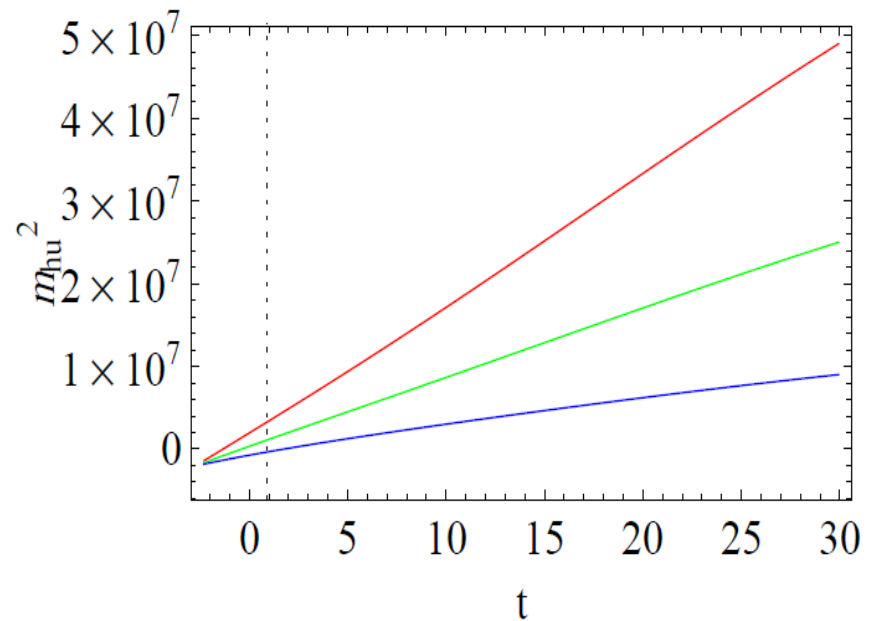


FIG. 1: RG evolutions of $m_{h_u}^2$ for $m_0^2 = (7 \text{ TeV})^2$ [Red], $(5 \text{ TeV})^2$ [Green], and $(3 \text{ TeV})^2$ [Blue], and for (a) $\tan \beta = 5$ and (b) $\tan \beta = 50$, when $m_{1/2} = 1 \text{ TeV}$ and $A_0 = 0$. Here we take $\alpha_G = 1/25$. The unit of the vertical axis 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 $Q = 200 \text{ GeV}$ [$Q = 2 \times 10^{16} \text{ GeV}$]. 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) $\tan \beta$.



(a)



(b)

FIG. 1: Running of the Higgs mass squared, m_{hu}^2 , versus the renormalization group parameter t for (a) $\tan \beta = 1$ and (b) $\tan \beta = 10$. The unit is 10^7 . The decoupling scale, $\mathcal{Q} = 5$ TeV. $t \approx -2.5$ [$t \approx 29.9$] corresponds to $\mathcal{Q} = 200$ GeV [$\mathcal{Q} = 2 \times 10^6$ GeV]. Below the stop decoupling scale, the above RG runnings must be modified. The above figures show that the extrapolated FP, where m_{hu}^2 is negative, appears at a relatively higher (lower) energy scale for small (large) $\tan \beta$.

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

ue], and
= 1/25.
ed stop
6 GeV].

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,

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

$$C_s, C_g (> 0)$$

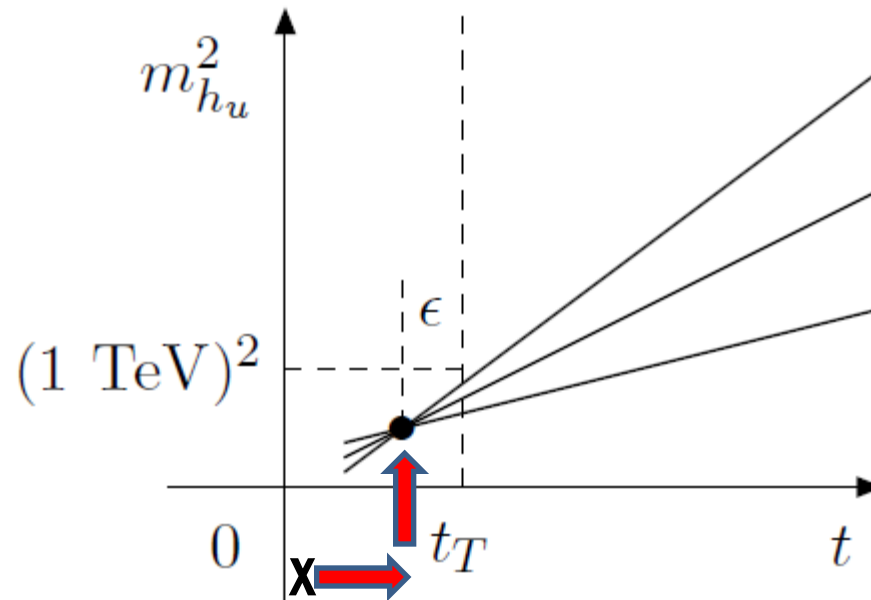
$C_g m_{1/2}^2$ needs to
be **SMALL** enough
for a small μ .

Below the stop mass scale

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

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

For predictively small EW scale



FP needs to **appear around stop mass scale (3-4 TeV),**
and **$|m_{h_u}^2| < (1 \text{ TeV})^2$ 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
Mediation”*

Minimal Gravity Mediation

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

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

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

Minimal Gravity Mediation

With the **minimal** Kahler pot. K , and superpot. W ,
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$$K = \sum_{i,a} |z_i|^2 + |\phi_a|^2 \quad W = W_H(z_i) + W_O(\phi_a)$$

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

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

Minimal Gravity Mediation

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

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

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

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

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,

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

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

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

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

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

Minimal Gravity Mediation

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

Universal Soft Masses:

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

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

A-terms $\propto m_0$

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

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A-terms $\propto m_0$

We set

$$A_0 \equiv a_Y m_0$$

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

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A-terms $\propto m_0$

Assume

$$\mathbf{f}_{ab} = \delta_{ab}$$

So **$\mathbf{M}_a = 0$**
at tree level.

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

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

$$\mathbf{f}_{ab} = \delta_{ab}$$

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

Minimal Gauge Mediation

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

$$W_m = y_S S \mathbf{5} \mathbf{5}^*$$

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

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*}**,

Non-universal

(dep. on flavors)

Soft Mass corrections !!

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

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Minimal Gauge Mediation

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

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

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

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$$M_a = \frac{g_a^2}{16\pi^2} \left[\frac{\langle F_S \rangle}{M_P} \right]^2 C_a(i)$$

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

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

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

where $C_a(i)$ is the quadratic Casimir of the representation i of the gauge group G_a , $(T^a T^a)_i^j = C_a(i) \delta_i^j$

Minimal Gauge Mediation

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

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

$$\langle S \rangle = \langle 24_H \rangle$$

ONE SUSY
breaking source
but
TWO mediations

$$M_a = \frac{g_a^2}{16\pi^2} \left[\frac{\langle F_{5^*} \rangle}{m} + \frac{\langle F_S \rangle}{m} \right]^2 C_a(i)$$

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

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

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

where $C_a(i)$ is the quadratic Casimir of the representation i of the gauge group G_a , $(T^a T^a)_i^j = C_a(i) \delta_i^j$

Minimal Gauge Mediation

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

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

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

$$M_a = \frac{g_a^2}{16\pi^2} \left[\frac{\langle F_S \rangle}{M_P} \right]^2 C_a(i)$$

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

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

$$\mathcal{O}(m M_P)$$

where $C_a(i)$ is the quadratic Casimir of the representation $\mathbf{R}_a$ of the gauge group G_a in the representation $\mathbf{R}_i$ of the messenger fields, i.e. $(T^a T^a)_i^j = C_a(i) \delta_i^j$.

Minimal Gauge Mediation

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

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

$$\langle S \rangle = \langle 24_H \rangle$$

Assoc. w/
C.C. prob.

Possible by a
GUT Model

$$M_a = \frac{g_a^2}{16\pi^2} \frac{\langle F_S \rangle}{M_P}$$

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

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

$$C_a(i)$$

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

where $C_a(i)$ is the quark

Minimal Gauge Mediation

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

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

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

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

$$\langle F_S \rangle / 16\pi^2 \langle S \rangle = \mathbf{f_s m_0}$$

where $C_a(i)$ is the quadratic Casimir of the representation i of the gauge group a , $(T^a T^a)_i^j = C_a(i) \delta_i^j$

Minimal Gauge Mediation

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

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

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

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

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

where $C_a(i)$ is the quadratic Casimir of the representation i of the gauge group G , $(T^a T^a)_i^j = C_a(i) \delta_i^j$

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.

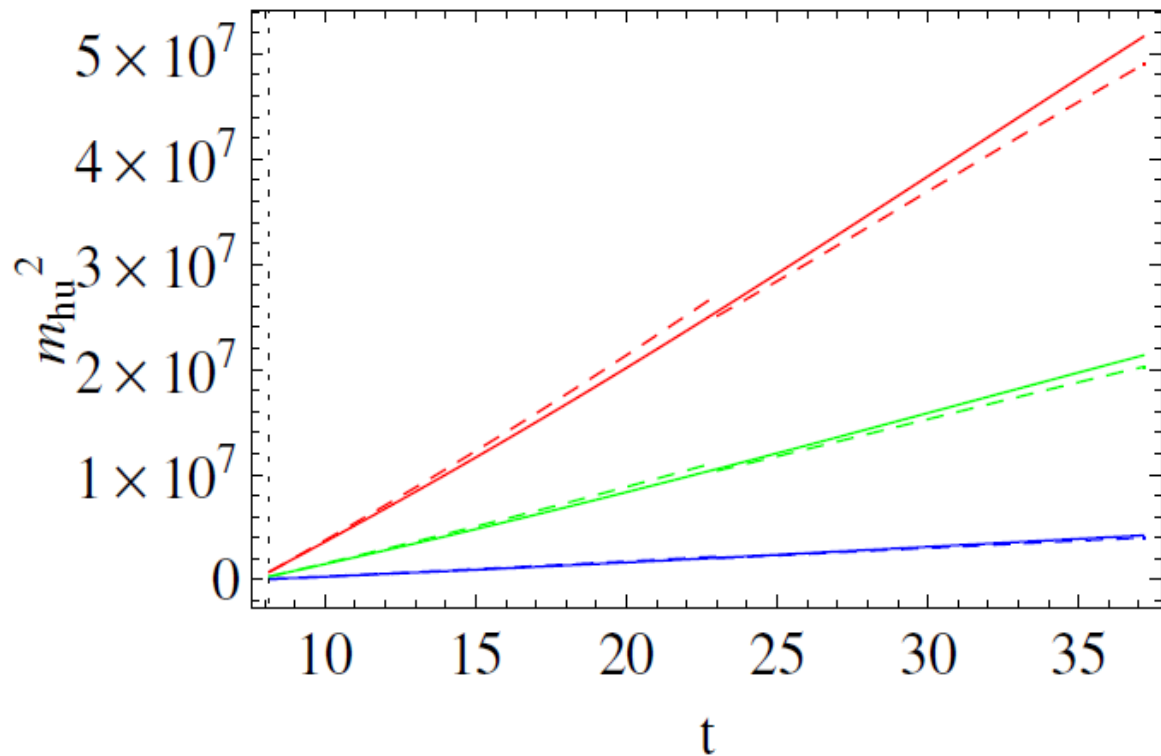


FIG. 1. RG evolutions of $m_{h_u}^2$ with t [$\equiv \log(Q/\text{GeV})$] for $m_0^2 = (7 \text{ TeV})^2$ [Red], $(4.5 \text{ TeV})^2$ [Green], and $(2 \text{ TeV})^2$ [Blue] when $A_t = -0.2 m_0$ and $\tan \beta = 50$. The tilted straight [dotted] lines correspond to the case of $t_M \approx 37$ (or $Q_M \approx 1.3 \times 10^{16} \text{ GeV}$, “Case A”) [$t_M \approx 23$ (or $Q_M = 1.0 \times 10^{10} \text{ GeV}$, “Case B”)]. The vertical dotted line at $t = t_T \approx 8.2$ ($Q_T = 3.5 \text{ TeV}$) indicates the desired stop decoupling scale. The discontinuities of $m_{h_u}^2(t)$ should appear at the messenger scales.

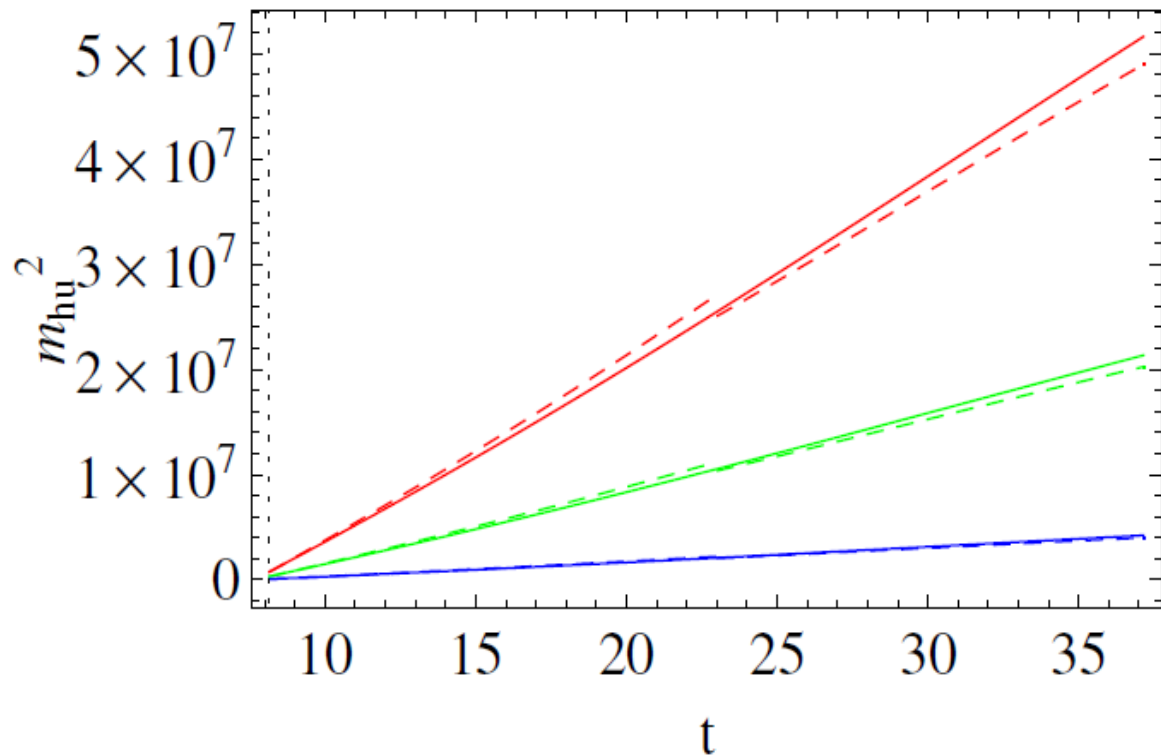


FIG. 1. RG evolutions of $m_{h_u}^2$ with $m_0 = (7 \text{ TeV})^2$ [Red], $(4.5 \text{ TeV})^2$ [Green], and $(3.5 \text{ TeV})^2$ [Blue] for $A_t = -0.2 m_0$ and $\tan \beta = 10$. The solid (dashed) lines correspond to the case of $t_M \approx 23$ (or $Q_M \approx 1.3 \times 10^{16} \text{ GeV}$, “Case A”) [$t_M \approx 23$ (or $Q_M = 1.0 \times 10^{10} \text{ GeV}$, “Case B”)]. The vertical dotted line at $t = t_T \approx 8.2$ ($Q_T = 3.5 \text{ TeV}$) indicates the desired stop decoupling scale. The discontinuities of $m_{h_u}^2(t)$ should appear at the messenger scales.

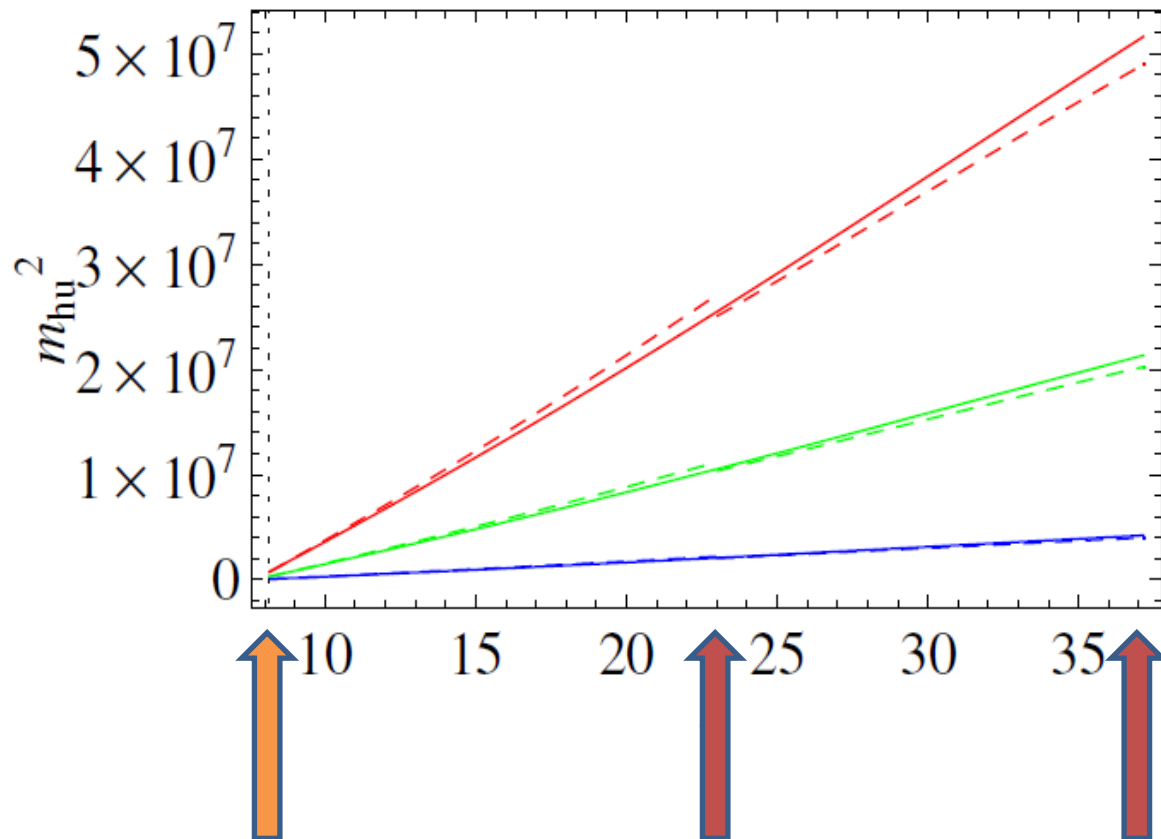


FIG. 1. The squared mass $m_{h_u}^2$ versus time t for $m_0^2 = (10^5 \text{ GeV})^2$ [GeV] when $A_t = -0.2 m_0$ and $\tan \beta = 50$. The tilted straight [dotted] lines correspond to the case of $t_M \approx 37$ (or $Q_M \approx 1.3 \times 10^{16} \text{ GeV}$, “Case A”) [$t_M \approx 23$ (or $Q_M = 1.0 \times 10^{10} \text{ GeV}$, “Case B”)]. The vertical dotted line at $t = t_T \approx 8.2$ ($Q_T = 3.5 \text{ TeV}$) indicates the desired stop decoupling scale. The discontinuities of $m_{h_u}^2(t)$ should appear at the messenger scales.

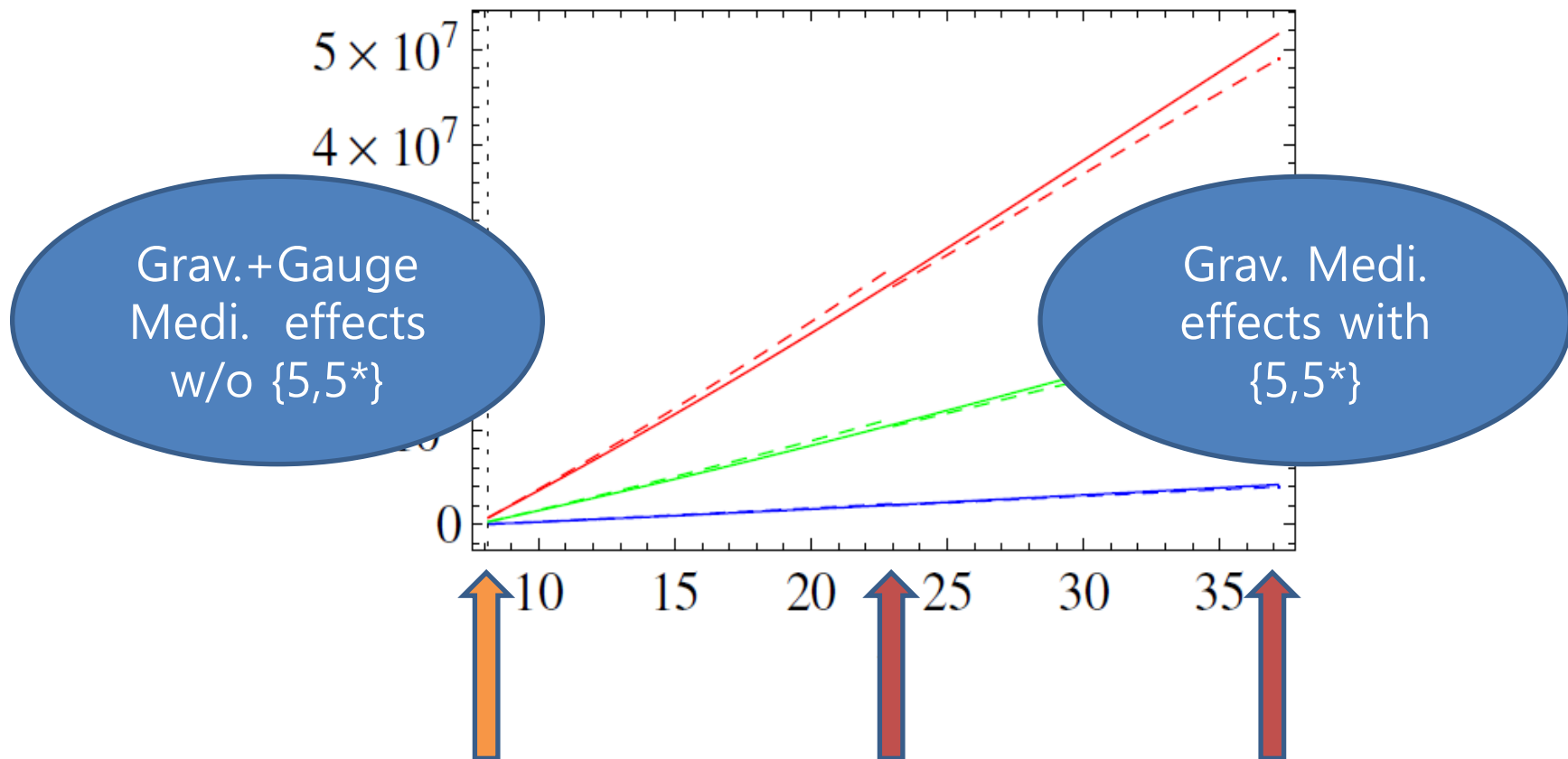


FIG. $m_{h_u}^2$ w/ $m_0^2 = (10^5 \text{ GeV})^2$ [Grav. Medi. effects] for $A_t = -0.2 m_0$ and $\tan \beta = 50$. The tilted straight [dotted] lines correspond to the case of $t_M \approx 37$ (or $Q_M \approx 1.3 \times 10^{16} \text{ GeV}$, “Case A”) [$t_M \approx 23$ (or $Q_M = 1.0 \times 10^{10} \text{ GeV}$, “Case B”)]. The vertical dotted line at $t = t_T \approx 8.2$ ($Q_T = 3.5 \text{ TeV}$) indicates the desired stop decoupling scale. The discontinuities of $m_{h_u}^2(t)$ should appear at the messenger scales.

**Regardless of the
Messenger Scales,
a Focus Point
appears at 3-4 TeV.**

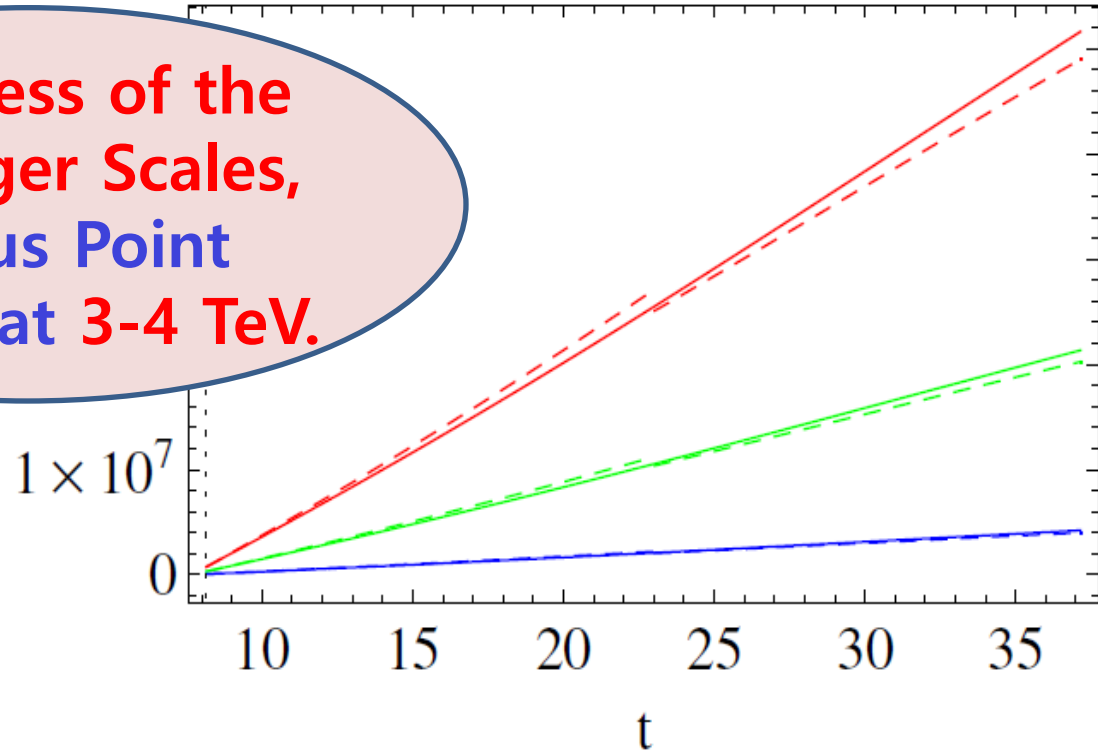


FIG. 1. RG evolutions of $m_{h_u}^2$ with $t [\equiv \log(Q/\text{GeV})]$ for $m_0^2 = (7\text{ TeV})^2$ [Red], $(4.5\text{ TeV})^2$ [Green], and $(2\text{ TeV})^2$ [Blue] when $A_t = -0.2 m_0$ and $\tan\beta = 50$. The tilted straight [dotted] lines correspond to the case of $t_M \approx 37$ (or $Q_M \approx 1.3 \times 10^{16}$ GeV, “Case A”) [$t_M \approx 23$ (or $Q_M = 1.0 \times 10^{10}$ GeV, “Case B”)]. The vertical dotted line at $t = t_T \approx 8.2$ ($Q_T = 3.5\text{ TeV}$) indicates the desired stop decoupling scale. The discontinuities of $m_{h_u}^2(t)$ should appear at the messenger scales.

at
 $Q_T = 3.5 \text{ TeV}$

for various
trial m_0^2 s

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

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
 $Q_T = 3.5 \text{ TeV}$

for various
trial m_0^2 s

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

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
 $Q_T = 3.5 \text{ TeV}$

for various
trial m_0^2 s

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

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
 $Q_T = 3.5 \text{ TeV}$

for various
trial m_0^2 s

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

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
 $Q_T = 3.5 \text{ TeV}$

for various
trial m_0^2 s

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

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
 $Q_T = 3.5 \text{ TeV}$

for various
trial m_0^2 s

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

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	$(5.5 \text{ TeV})^2$	$(4.5 \text{ TeV})^2$	$(3.5 \text{ TeV})^2$
$m_{q_3}^2(t_T)$	$(4389 \text{ GeV})^2$	$(3575 \text{ GeV})^2$	$(2760 \text{ GeV})^2$
$m_{u_3^c}^2(t_T)$	$(3810 \text{ GeV})^2$	$(3118 \text{ GeV})^2$	$(2421 \text{ GeV})^2$
$m_{h_u}^2(t_T)$	$(647 \text{ GeV})^2$	$(423 \text{ GeV})^2$	$-(56 \text{ GeV})^2$
$m_{h_d}^2(t_T)$	$(2084 \text{ GeV})^2$	$(1577 \text{ GeV})^2$	$(1054 \text{ GeV})^2$
Case IV	$A_t = -1.0 m_0$	$\tan \beta = 50$	$\Delta_{m_0^2} = 57$
m_0^2	$(5.5 \text{ TeV})^2$	$(4.5 \text{ TeV})^2$	$(3.5 \text{ TeV})^2$
$m_{q_3}^2(t_T)$	$(4402 \text{ GeV})^2$	$(3587 \text{ GeV})^2$	$(2768 \text{ GeV})^2$
$m_{u_3^c}^2(t_T)$	$(3823 \text{ GeV})^2$	$(3130 \text{ GeV})^2$	$(2429 \text{ GeV})^2$
$m_{h_u}^2(t_T)$	$(152 \text{ GeV})^2$	$-(220 \text{ GeV})^2$	$-(293 \text{ GeV})^2$
$m_{h_d}^2(t_T)$	$(5057 \text{ GeV})^2$	$(4136 \text{ GeV})^2$	$(3215 \text{ GeV})^2$

For Case I, II, III, IV,

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

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

at
 $Q_T = 3.5 \text{ TeV}$

for various
trial m_0^2 s

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

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	$(5.5 \text{ TeV})^2$	$(4.5 \text{ TeV})^2$	$(3.5 \text{ TeV})^2$
$m_{q_3}^2(t_T)$	$(4389 \text{ GeV})^2$	$(3575 \text{ GeV})^2$	$(2760 \text{ GeV})^2$
$m_{u_3^c}^2(t_T)$	$(3810 \text{ GeV})^2$	$(3118 \text{ GeV})^2$	$(2421 \text{ GeV})^2$
$m_{h_u}^2(t_T)$	$(647 \text{ GeV})^2$	$(423 \text{ GeV})^2$	$-(59 \text{ GeV})^2$
$m_{h_d}^2(t_T)$	$(2084 \text{ GeV})^2$	$(1577 \text{ GeV})^2$	$(1054 \text{ GeV})^2$
Case IV	$A_t = +0.1 m_0$	$\tan \beta = 50$	$\Delta_{m_0^2} = 57$
m_0^2	$(5.5 \text{ TeV})^2$	$(4.5 \text{ TeV})^2$	$(3.5 \text{ TeV})^2$
$m_{q_3}^2(t_T)$	$(4402 \text{ GeV})^2$	$(3587 \text{ GeV})^2$	$(2768 \text{ GeV})^2$
$m_{u_3^c}^2(t_T)$	$(3823 \text{ GeV})^2$	$(3130 \text{ GeV})^2$	$(2429 \text{ GeV})^2$
$m_{h_u}^2(t_T)$	$(152 \text{ GeV})^2$	$-(220 \text{ GeV})^2$	$-(293 \text{ GeV})^2$
$m_{h_d}^2(t_T)$	$(5057 \text{ GeV})^2$	$(4136 \text{ GeV})^2$	$(3215 \text{ GeV})^2$

For $A_t/m_0 = +0.1$,

$\{\Delta_{m_0^2}, \Delta_{A_t}, |\mu|/\text{GeV}\} \approx \{22, 33, 570\}$

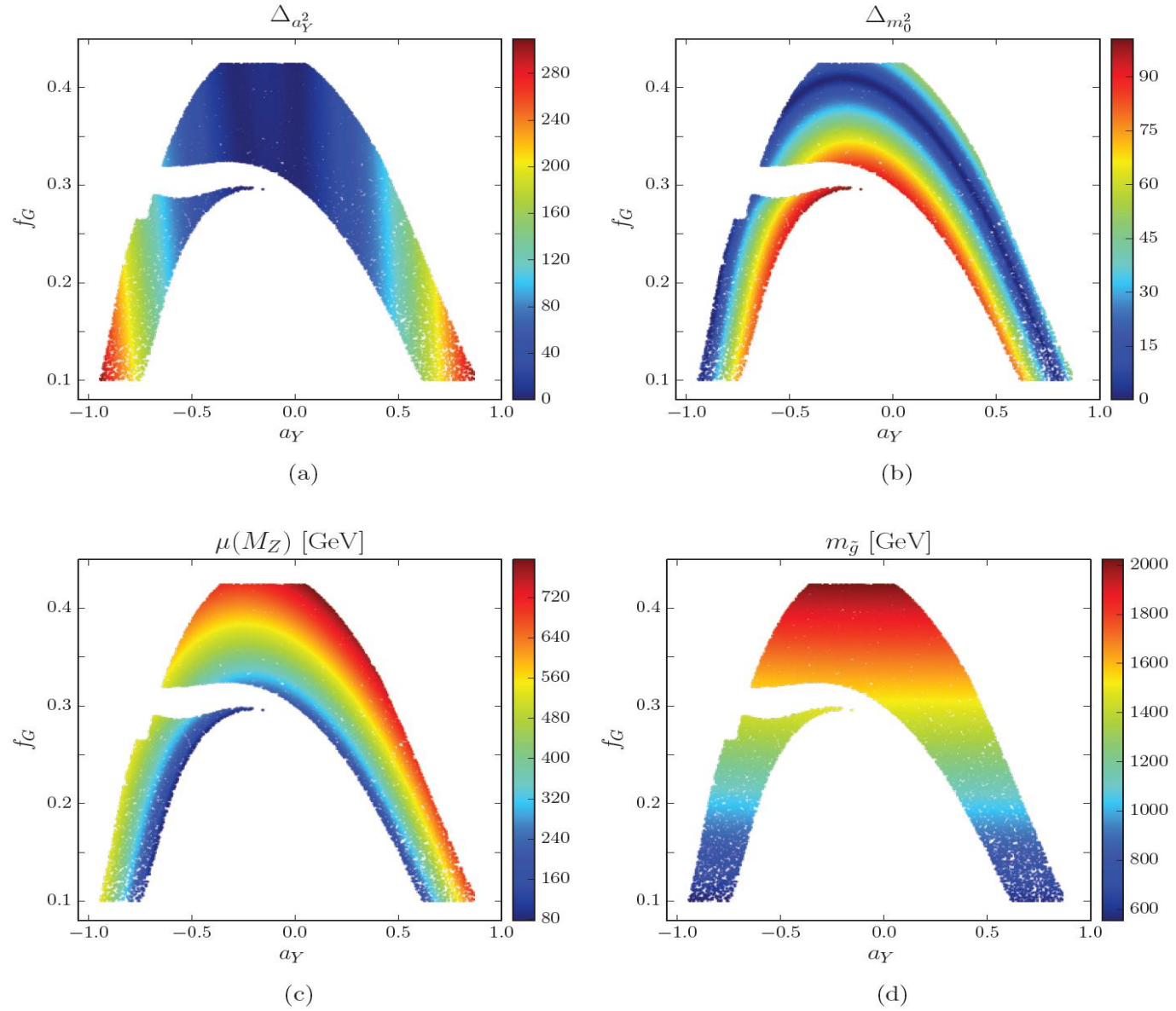


FIG. 4: Scatter plots for (a) Δa_Y^2 , (b) Δm_0^2 , and (c) $|\mu|$ at the M_Z scale, and (d) on-shell gluino mass when $m_0^2 = (4 \text{ TeV})^2$ and $\tan \beta = 50$. Here we set $M_G = 1.7 \times 10^{16} \text{ GeV}$. The stop mass scale is about 3.0 TeV.

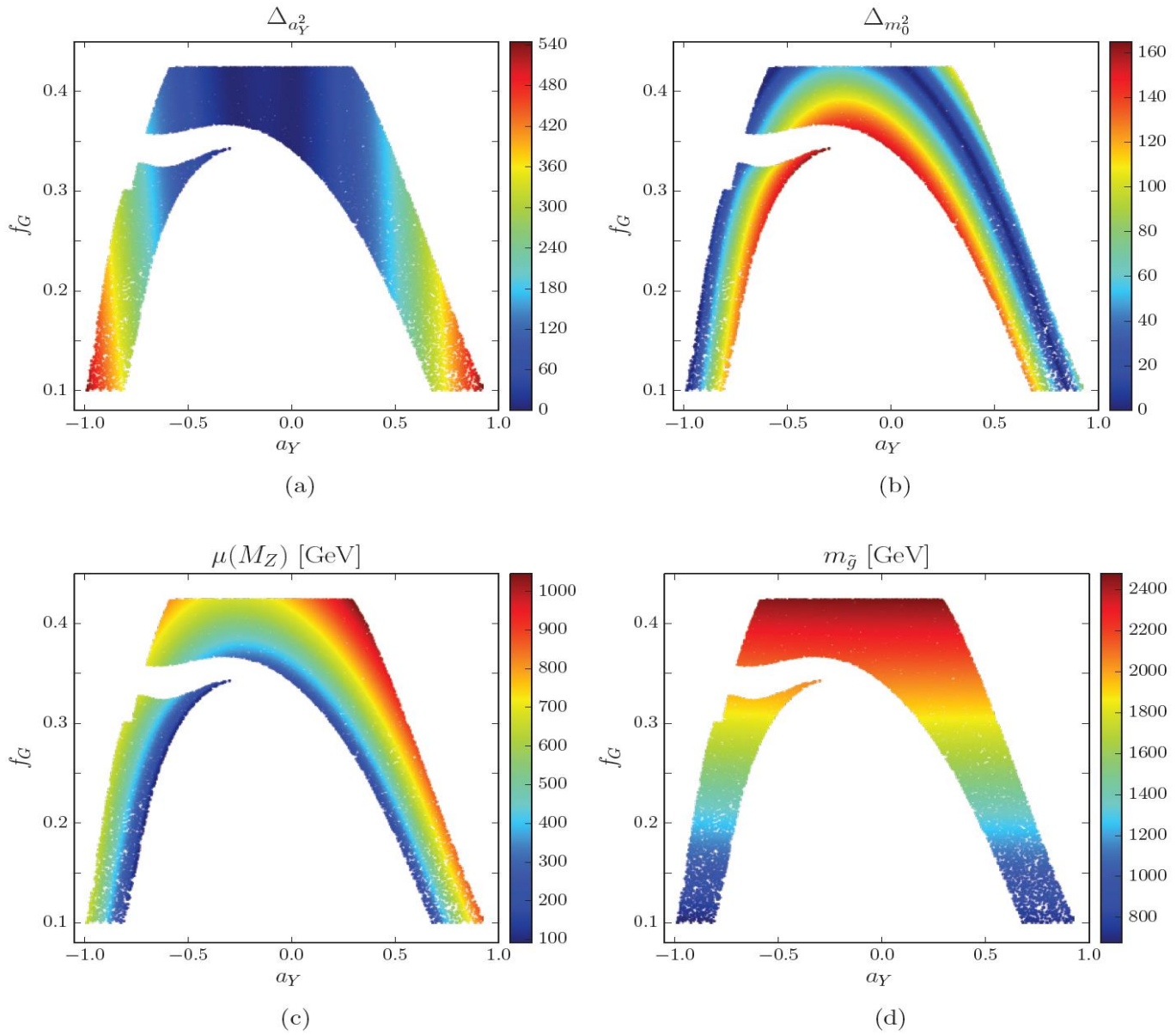


FIG. 5: Scatter plots for (a) Δa_Y^2 , (b) Δm_0^2 , and (c) $|\mu|$ at the M_Z scale, and (d) on-shell gluino mass when $m_0^2 = (5 \text{ TeV})^2$ and $\tan \beta = 50$. Here we set $M_G = 1.7 \times 10^{16} \text{ GeV}$. The stop mass scale is about 3.7 TeV.

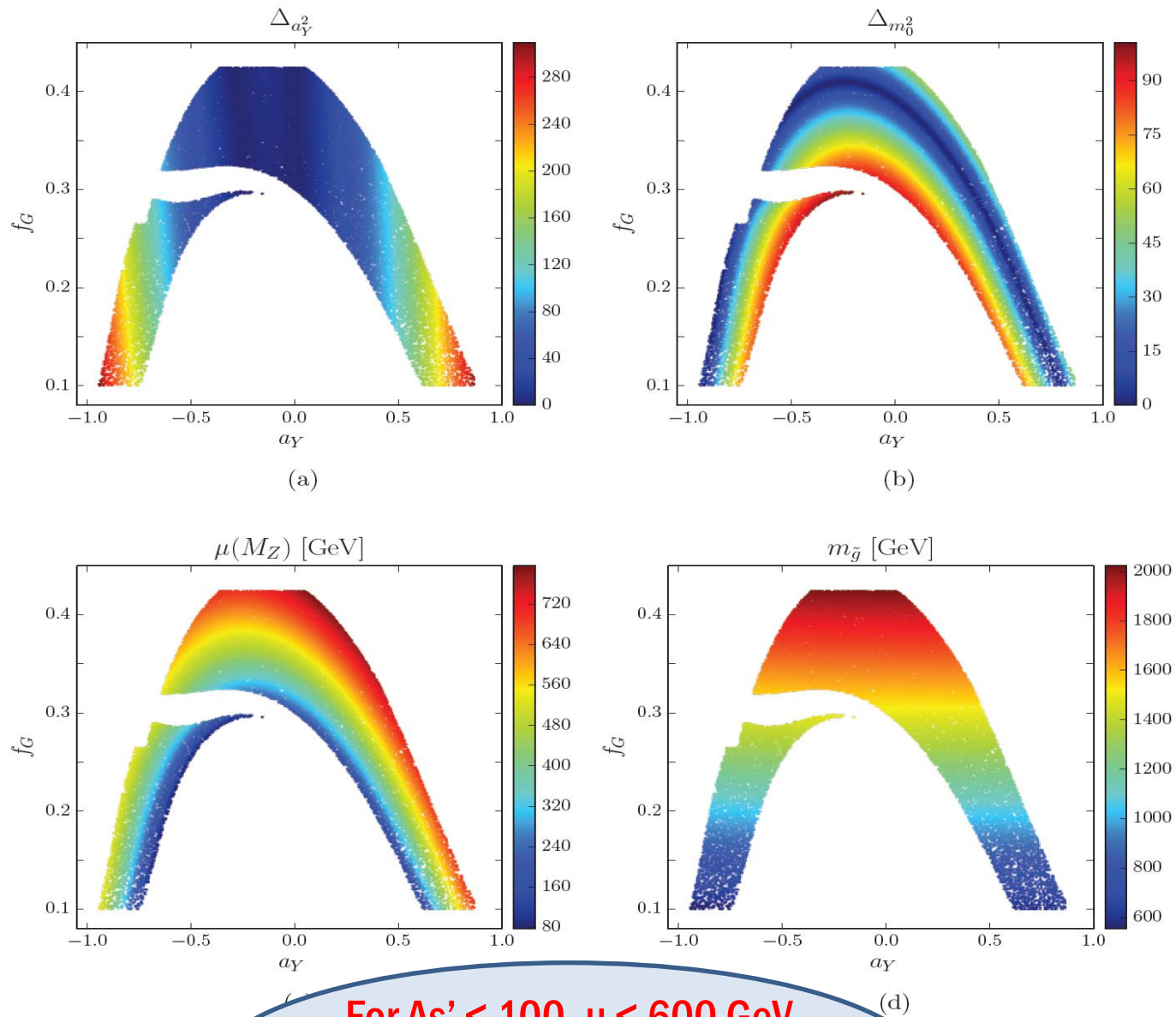


FIG. 4: Scatter plots of f_G versus a_Y for (a) $\Delta_{a_Y^2}$, (b) $\Delta_{m_0^2}$, (c) $\mu(M_Z)$, and (d) on-shell gluino mass $m_{\tilde{g}}$ when $\Delta_{a_Y^2} < 100$, $\mu < 600$ GeV, and $m_{\tilde{g}} < 2.7 \times 10^{16}$ GeV. The

For $\Delta_{a_Y^2} < 100$, $\mu < 600$ GeV

$-0.7 < a_Y < 0.5$

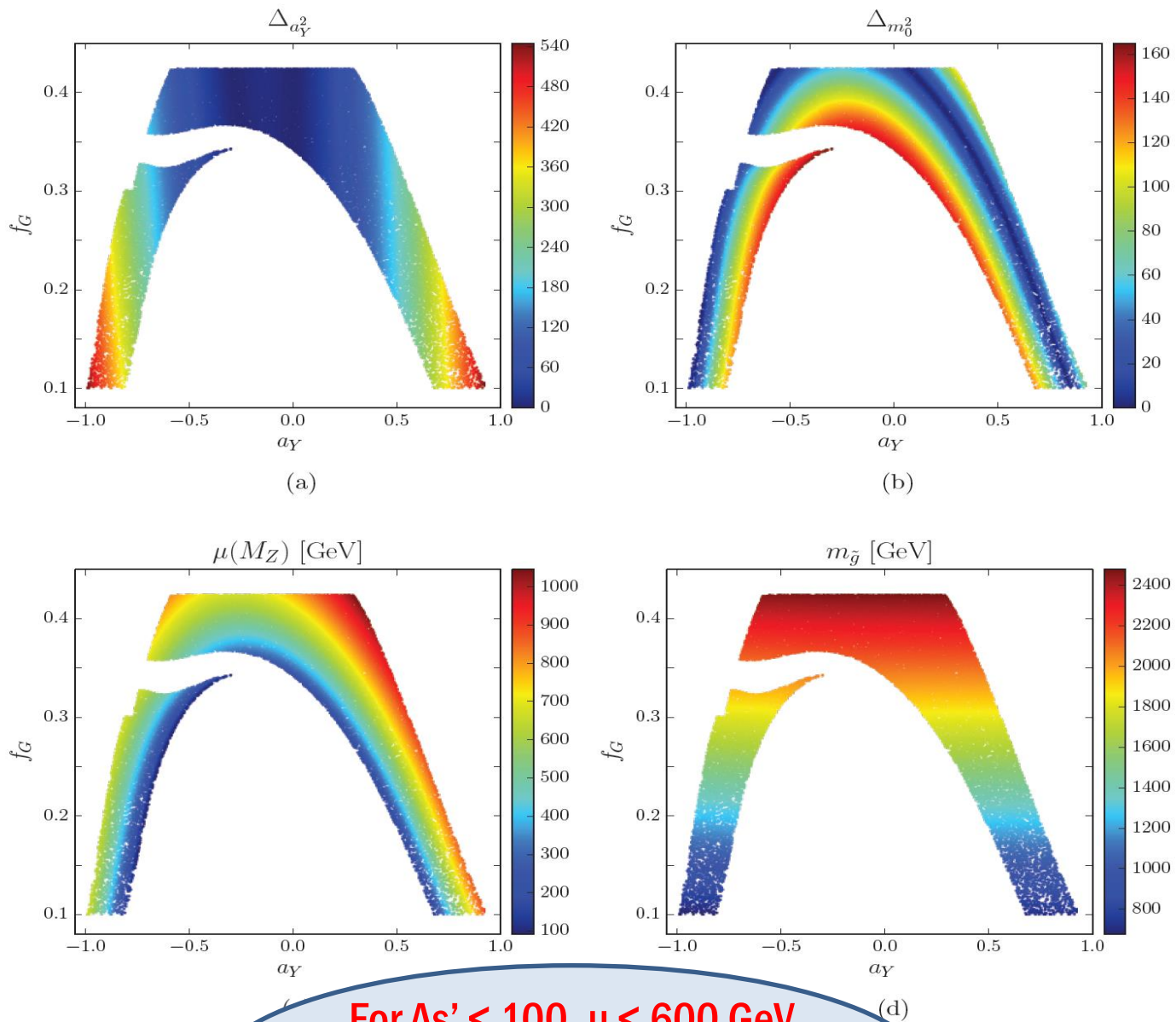


FIG. 5: Scatter plots of (a) $\Delta_{a_Y^2}$, (b) $\Delta_{m_0^2}$, (c) $\mu(M_Z)$, and (d) on-shell gluino mass $m_{\tilde{g}}$ versus a_Y and f_G for $\Delta_{a_Y^2} < 100$, $\mu < 600$ GeV, and $m_{\tilde{g}} < 2.7 \times 10^{16}$ GeV. The

For $\Delta_{a_Y^2} < 100$, $\mu < 600$ GeV

$0.3 < f_G < 0.4$

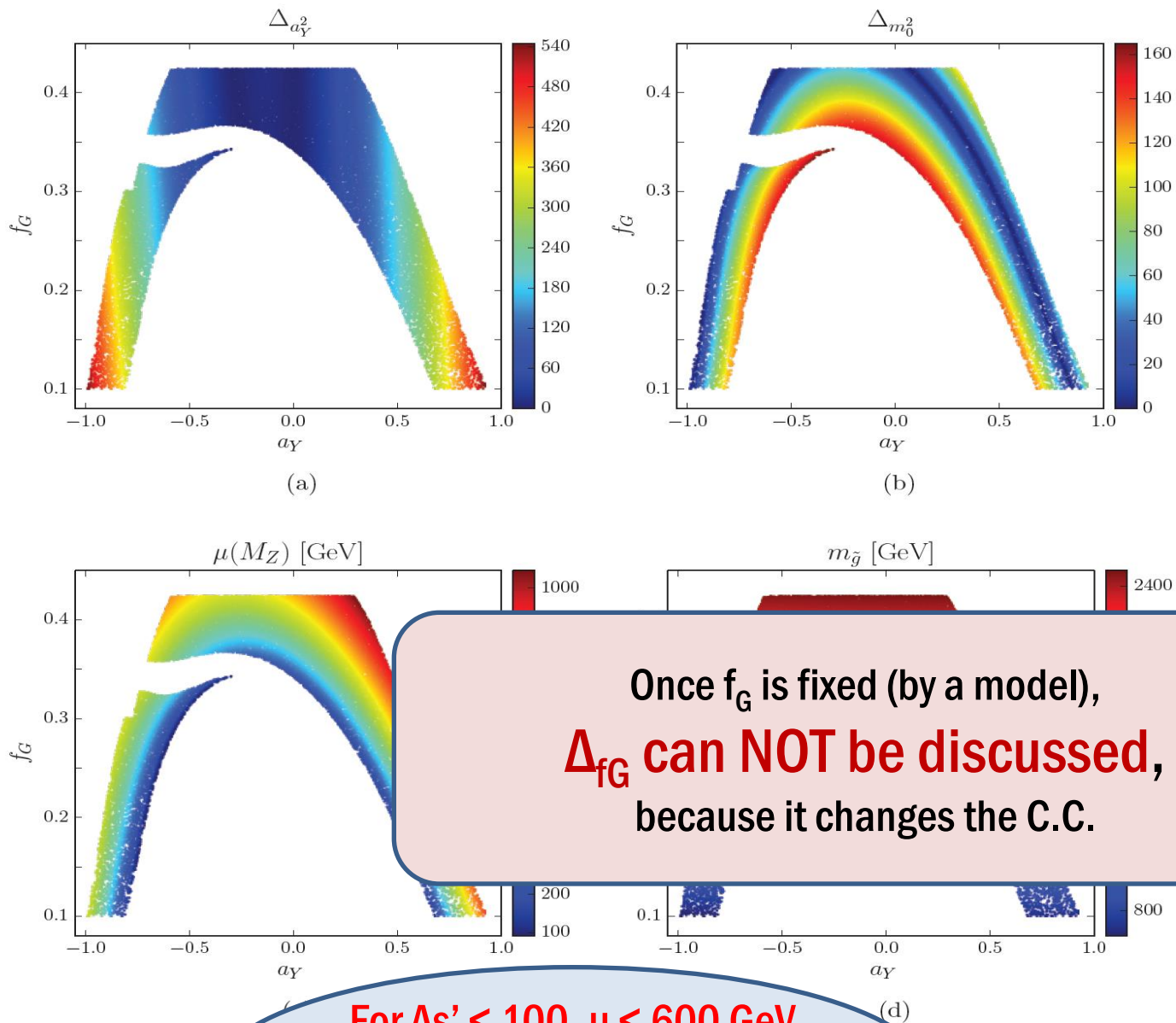


FIG. 5: Scatter plots of (a) Δa_Y^2 , (b) Δm_0^2 , (c) $\mu(M_Z)$, and (d) on-shell gluino mass $m_{\tilde{g}}$ as a function of a_Y and f_G for $\mu = 1.7 \times 10^{16}$ GeV. The

For $\Delta s' < 100$, $\mu < 600$ GeV

$0.3 < f_G < 0.4$

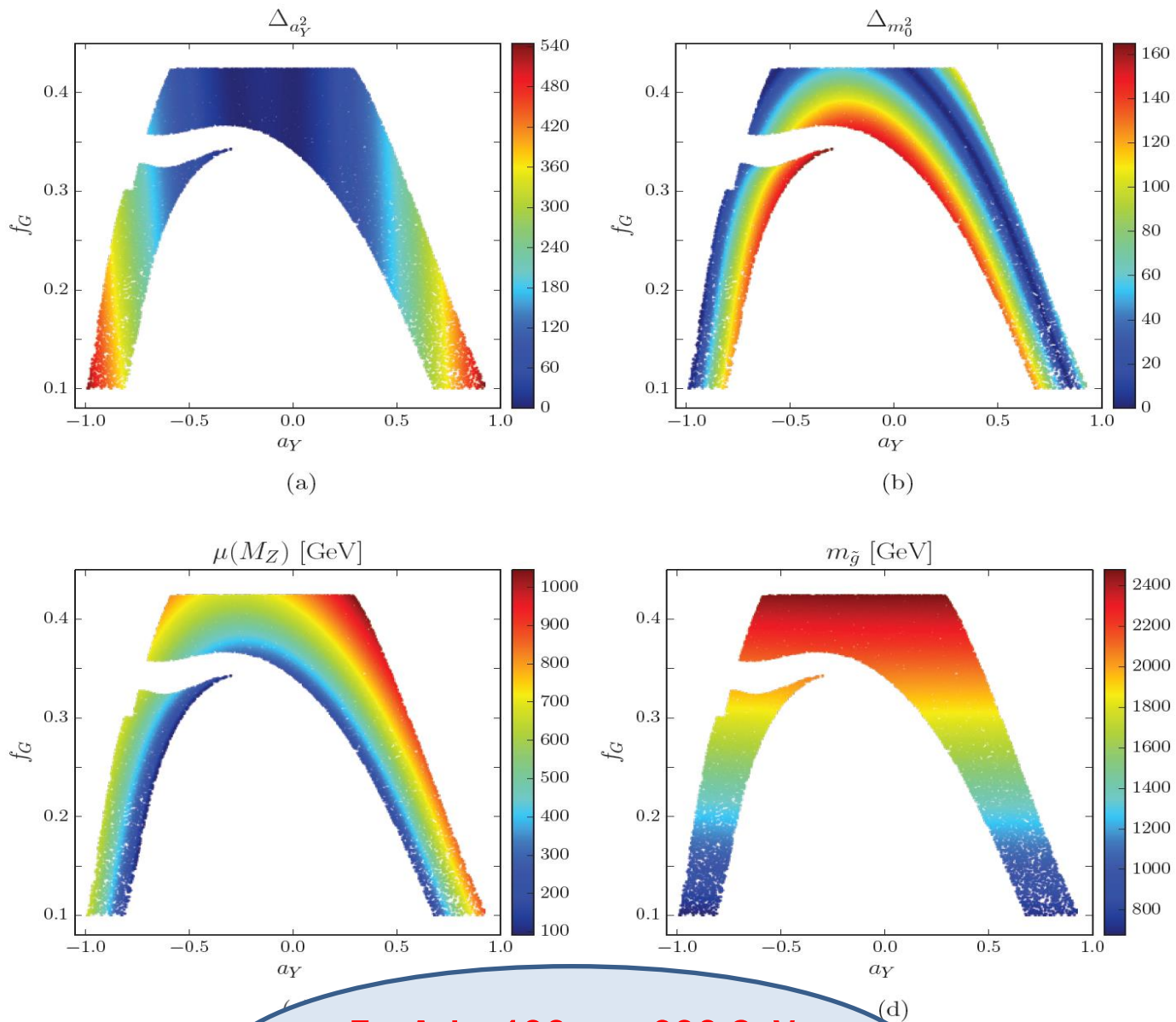


FIG. 5: Scatter plots of the gluino mass $m_{\tilde{g}}$ versus the mass of the lightest CP-even Higgs boson m_h for (a) off-shell $\tilde{g} \rightarrow t\bar{t}$, (b) off-shell $\tilde{g} \rightarrow b\bar{b}$, (c) off-shell $\tilde{g} \rightarrow \tau\bar{\tau}$, and (d) on-shell $\tilde{g} \rightarrow t\bar{t}$. The red shaded regions indicate the parameter space excluded by the LHC Run 2 results. The blue shaded regions indicate the parameter space excluded by the LHC Run 3 results. The green shaded regions indicate the parameter space excluded by the LHC Run 4 results. The black shaded regions indicate the parameter space excluded by the LHC Run 5 results.

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 $\approx (4\text{-}5 \text{ TeV})^2$, which yields**
3-4 TeV stop and 125 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.

SUSY particle masses

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

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

both Δm_0^2 and $\Delta A_t \ll 100$

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

SUSY particle masses

For

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

,

Even for

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

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

,

both

$$\Delta m_0^2$$

and

$$\Delta A_t$$

$\ll$

100

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

SUSY particle masses

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

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

$(m_{q_3}^2, m_{u_c^3}^2) = \mathbf{3 - 4 \text{ TeV}}$ 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 $m_0^2 \approx (4.5 \text{ TeV})^2$, $\tan \beta \gtrsim 25$, and

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

$(m_{q_3}^2, m_{u_3^c}^2) = \mathbf{3 - 4 \text{ TeV}}$ responsible for
126 GeV Higgs mass

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

SUSY particle masses

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

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

$$(m_{q_3}^2, m_{u_3^c}^2) = \mathbf{3 - 4 \text{ TeV}}$$

responsible for
125 GeV Higgs mass

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

sleptons , sbottom masses $> 3 - 4 \text{ TeV}$

SUSY particle masses

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

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

$(m_{q_3}^2, m_{u_c^3}^2) = \mathbf{3 - 4 \text{ TeV}}$ responsible for
125 GeV Higgs mass

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

$$|\mu| = \mathbf{390 \text{ GeV} - 590 \text{ GeV}} \text{ for } m_z = 91 \text{ GeV}$$