Dec 2 2013 “SUSY: Model-building and Phenomenology”

Indications of low energy SUSY

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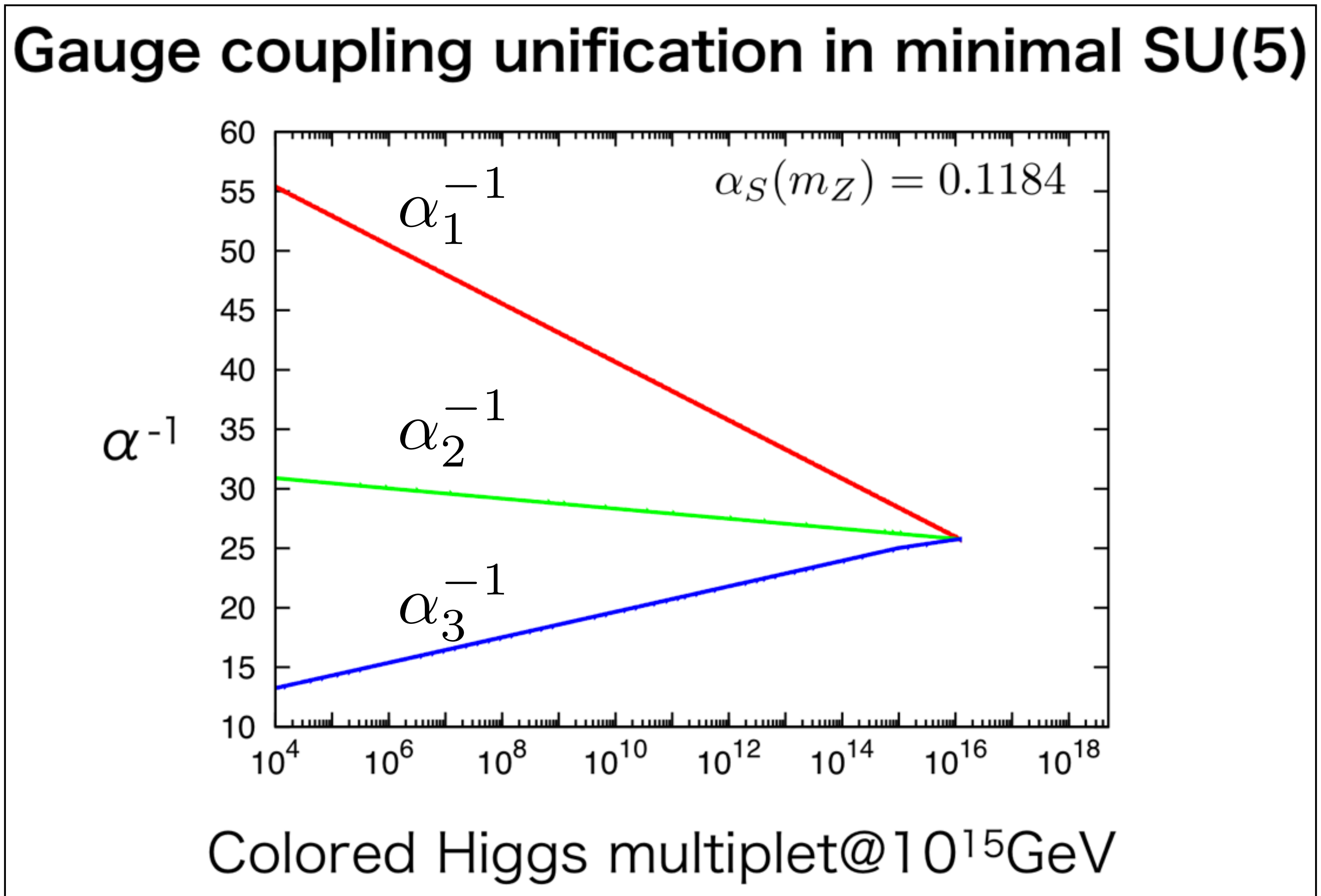
In collaboration with

1st part: T. Yanagida
2nd part: T. Yanagida, G. Bhattacharyya, B. Bhattacherjee

Why supersymmetry?

Why supersymmetry?

Gauge coupling unification



Why supersymmetry?

Understanding the origin of EWSB scale

Why supersymmetry?

Understanding the origin of EWSB scale

This picture works well if SUSY scale ~ EWSB scale

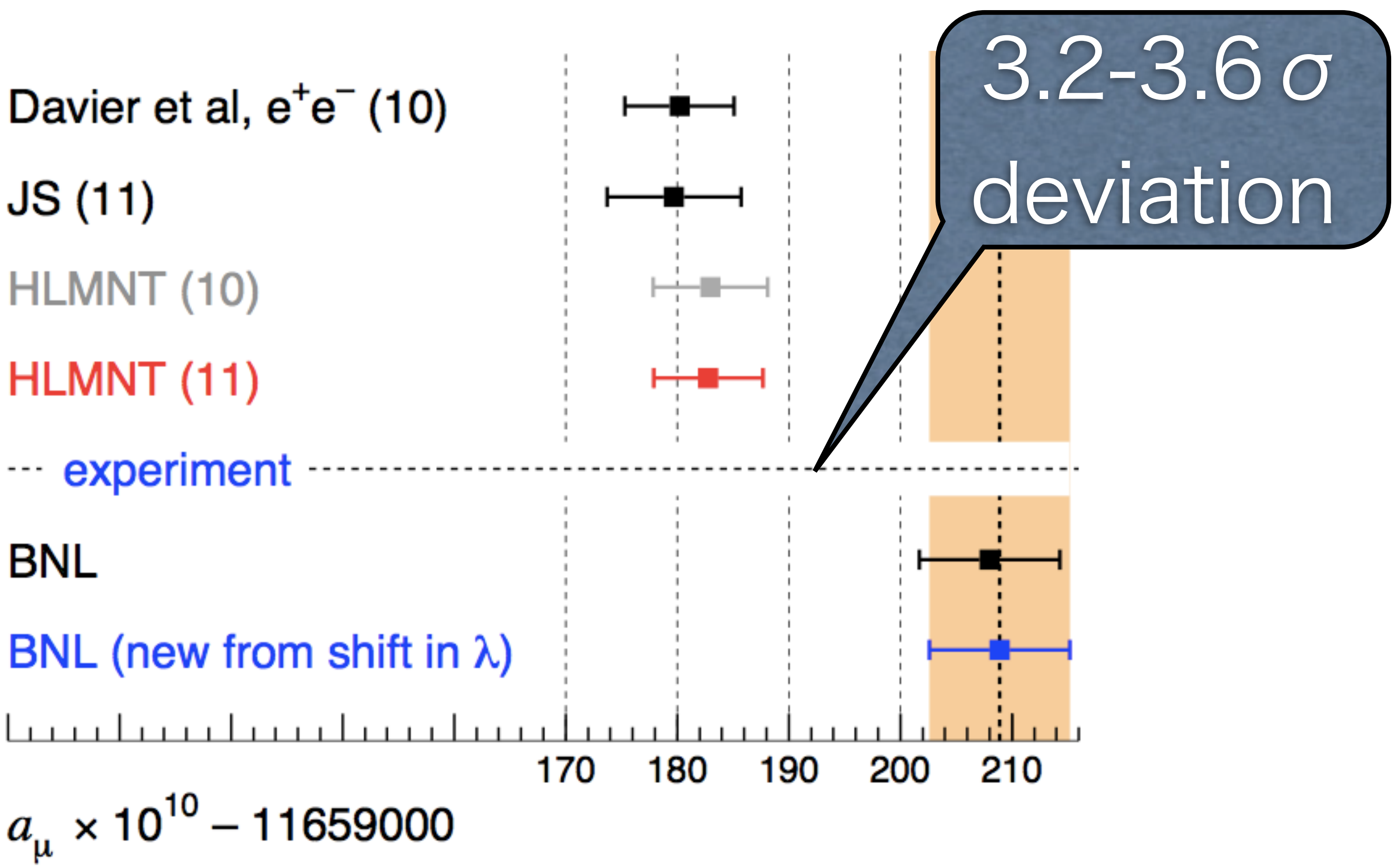
But, this picture seems not work very well in the current situation, i.e., SUSY particles are **heavy**

How can we understand the origin of the EWSB scale with relatively **heavy** SUSY particles?

First part

Why supersymmetry?

Anomaly of the muon g-2

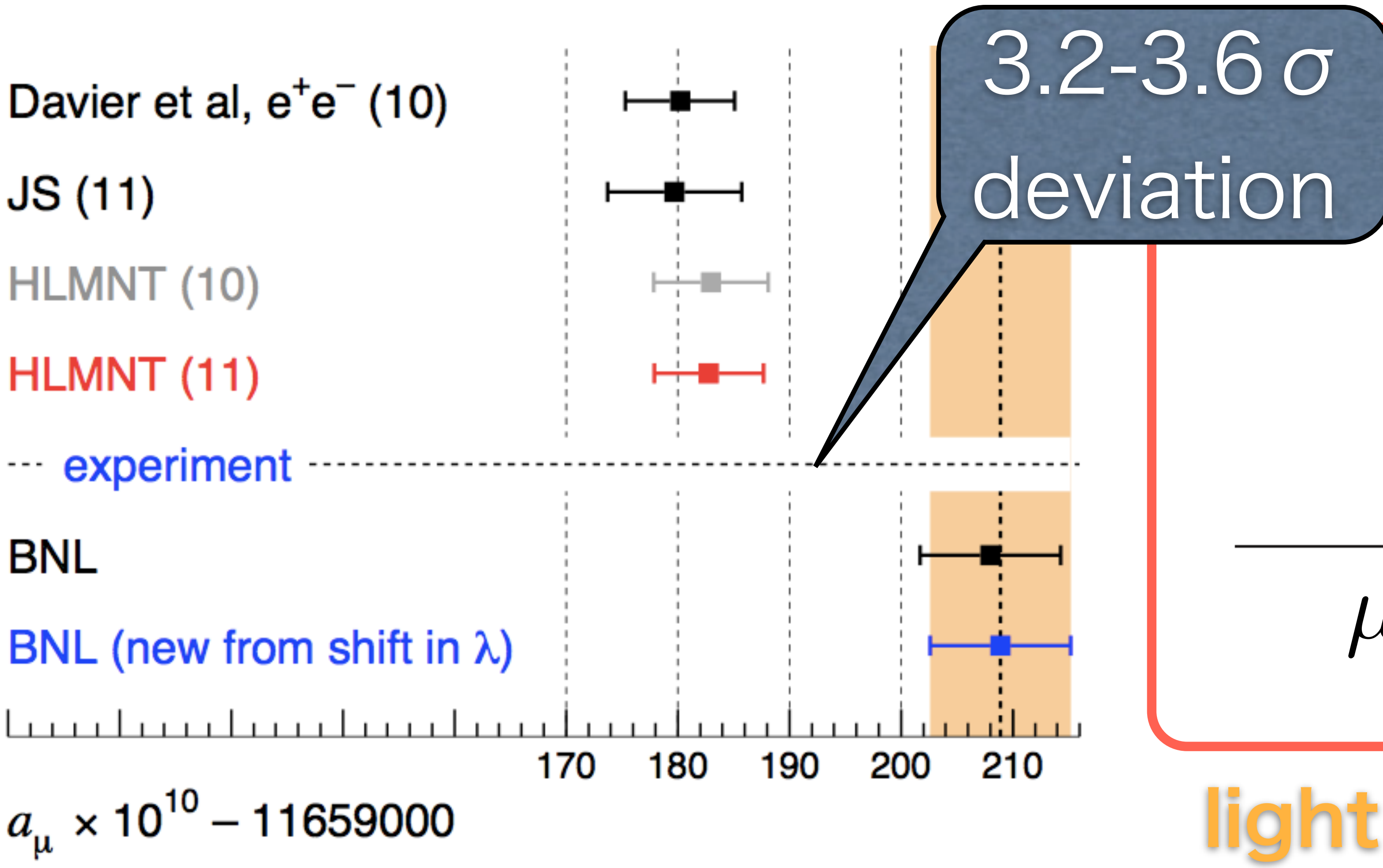


[Hagiwara, Liao, Martin, Nomura, Teubner, J.Phys. G38 (2011) 085003]

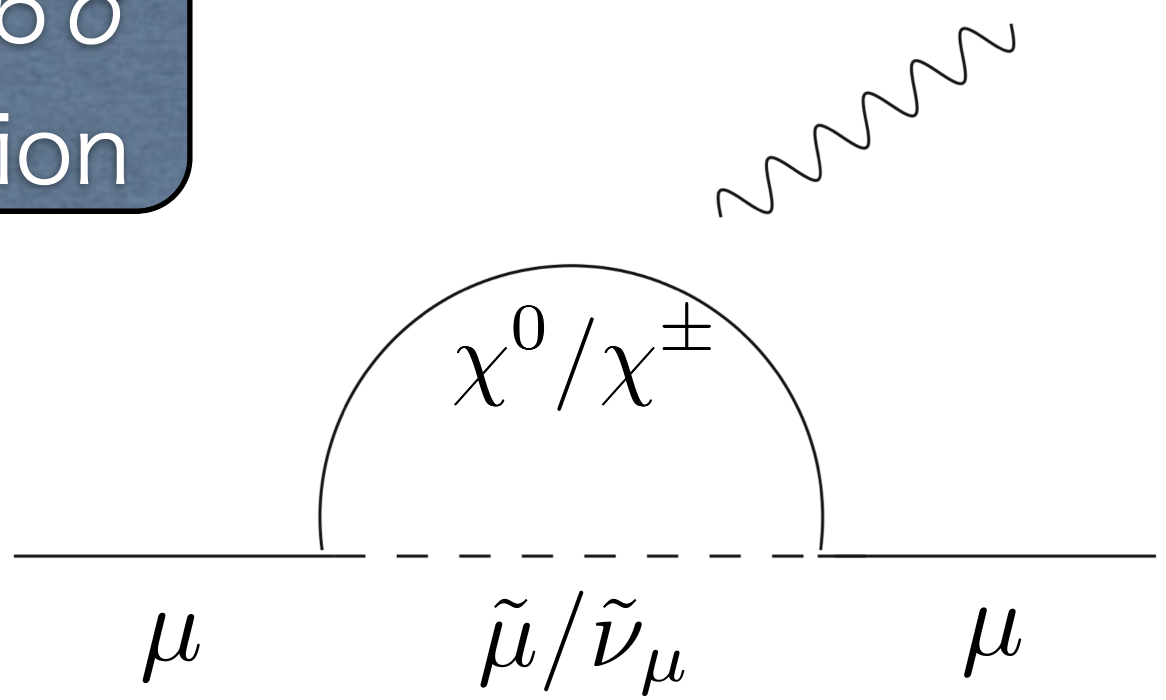
Why supersymmetry?

Anomaly of the muon g-2

2nd part



[Hagiwara, Liao, Martin, Nomura, Teubner, J.Phys. G38 (2011) 085003]



light smuon and nuetralino/ chargino can explain this discrepancy

First Part

Reconsideration of the fine-tuning problem

Radiative EWSB works very well for low-energy SUSY

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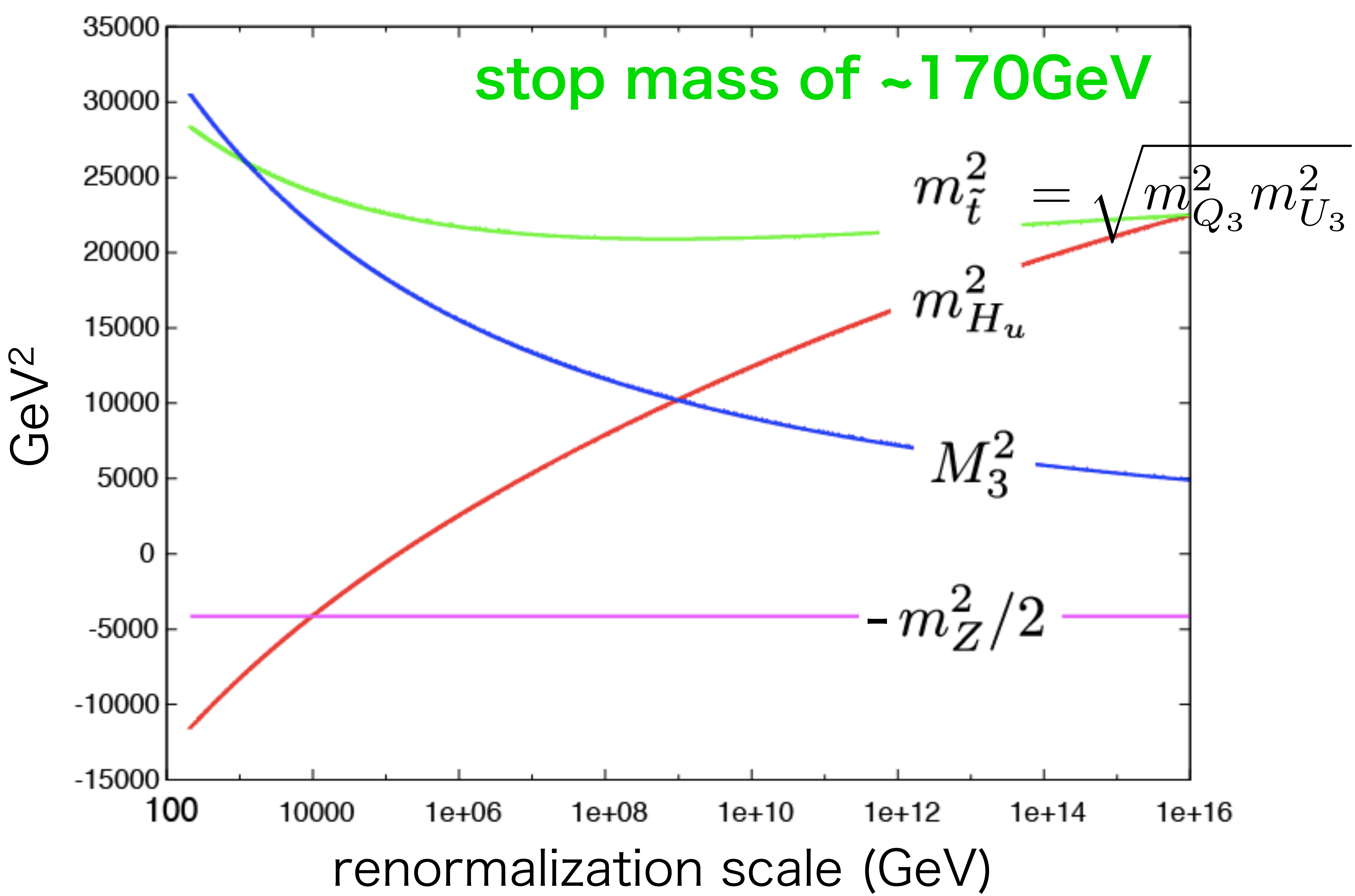

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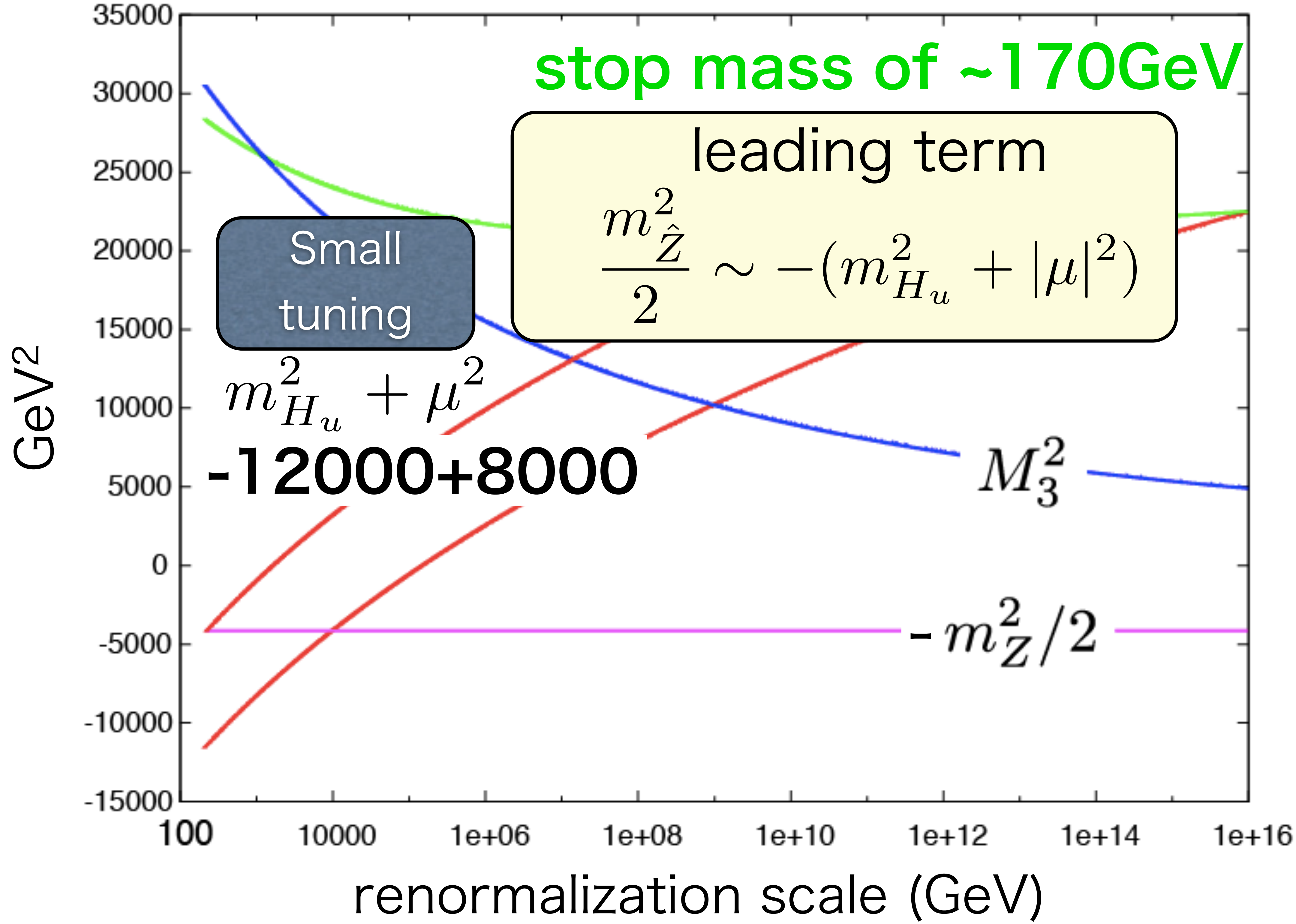

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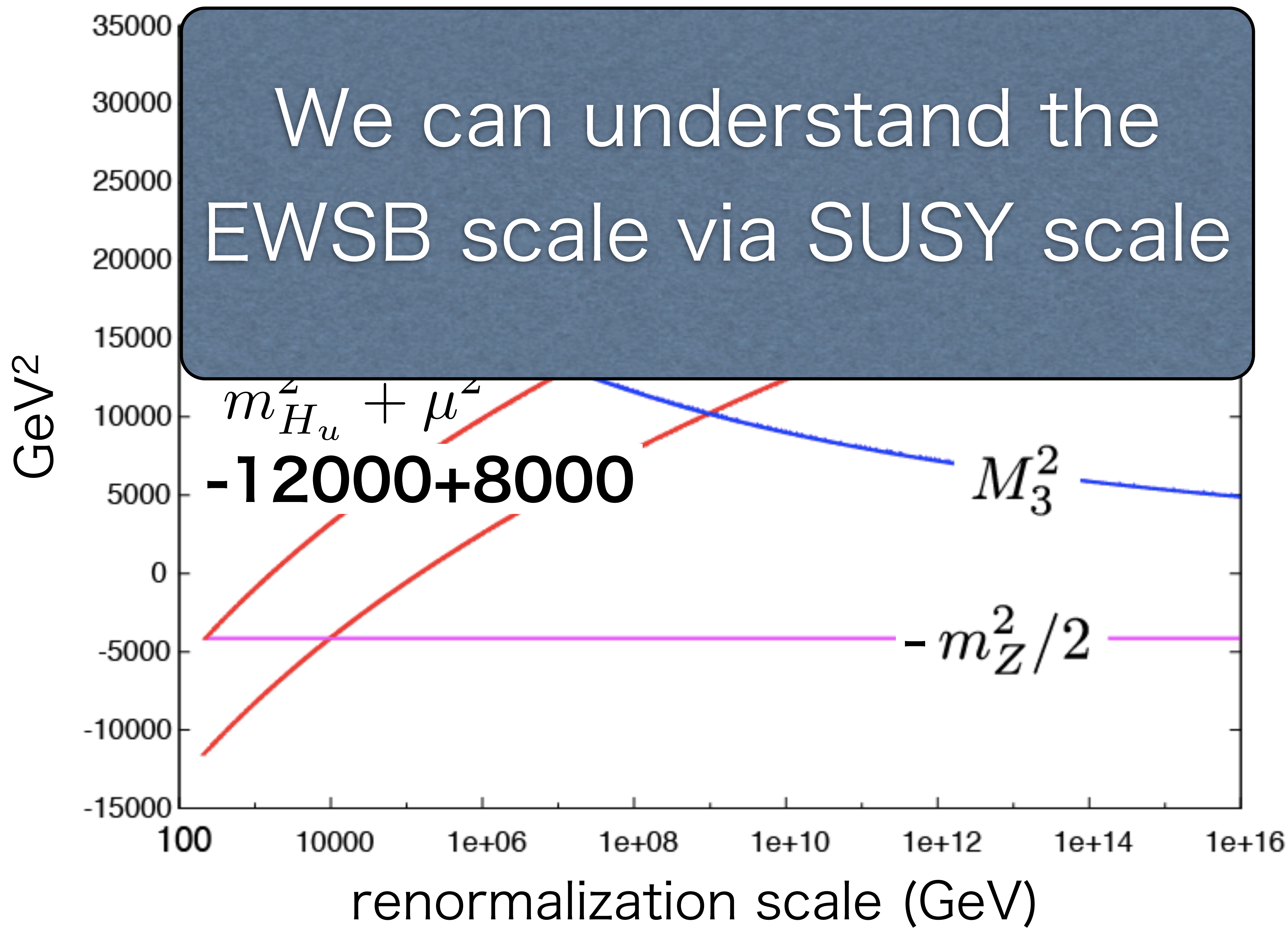

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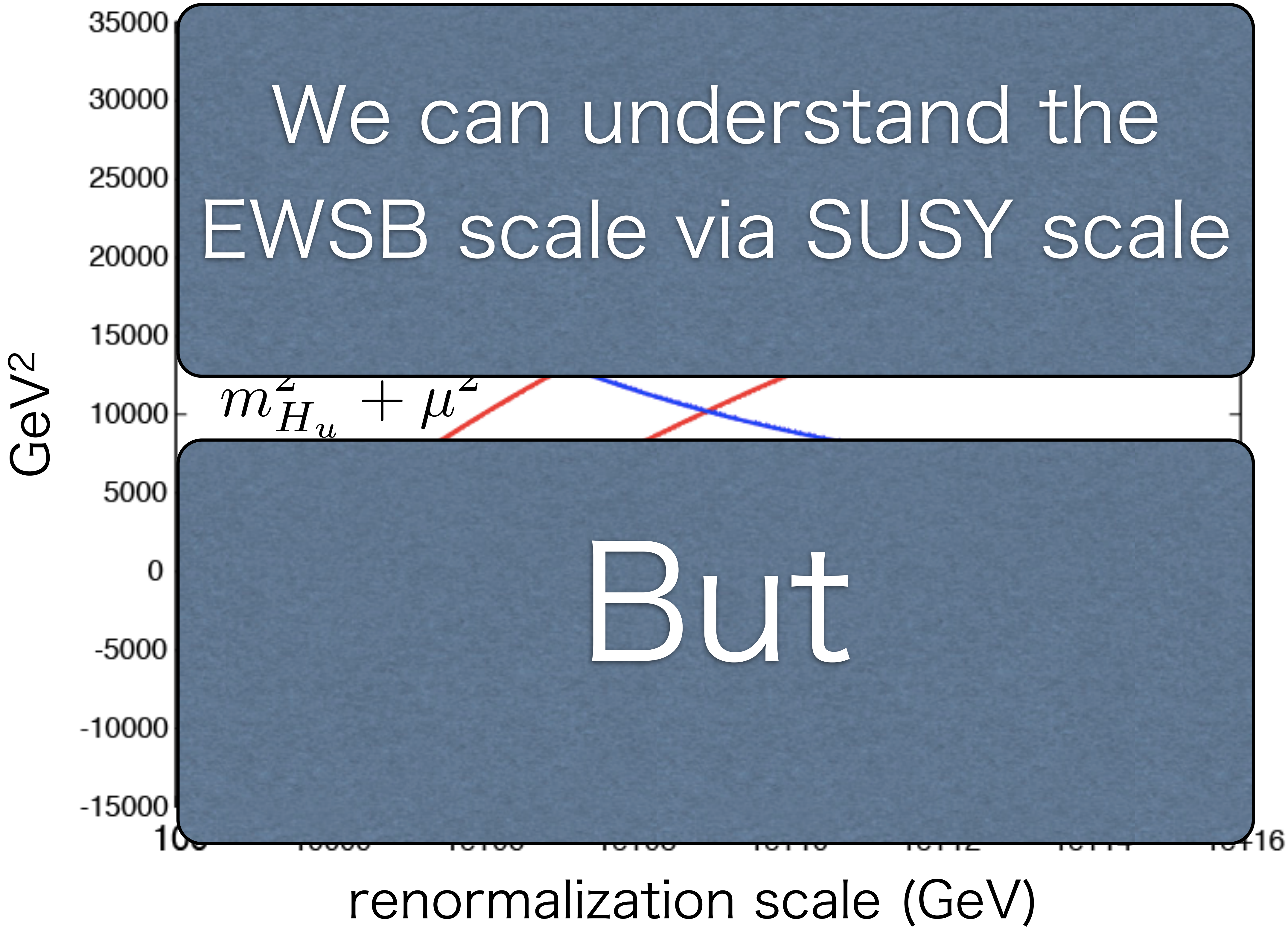


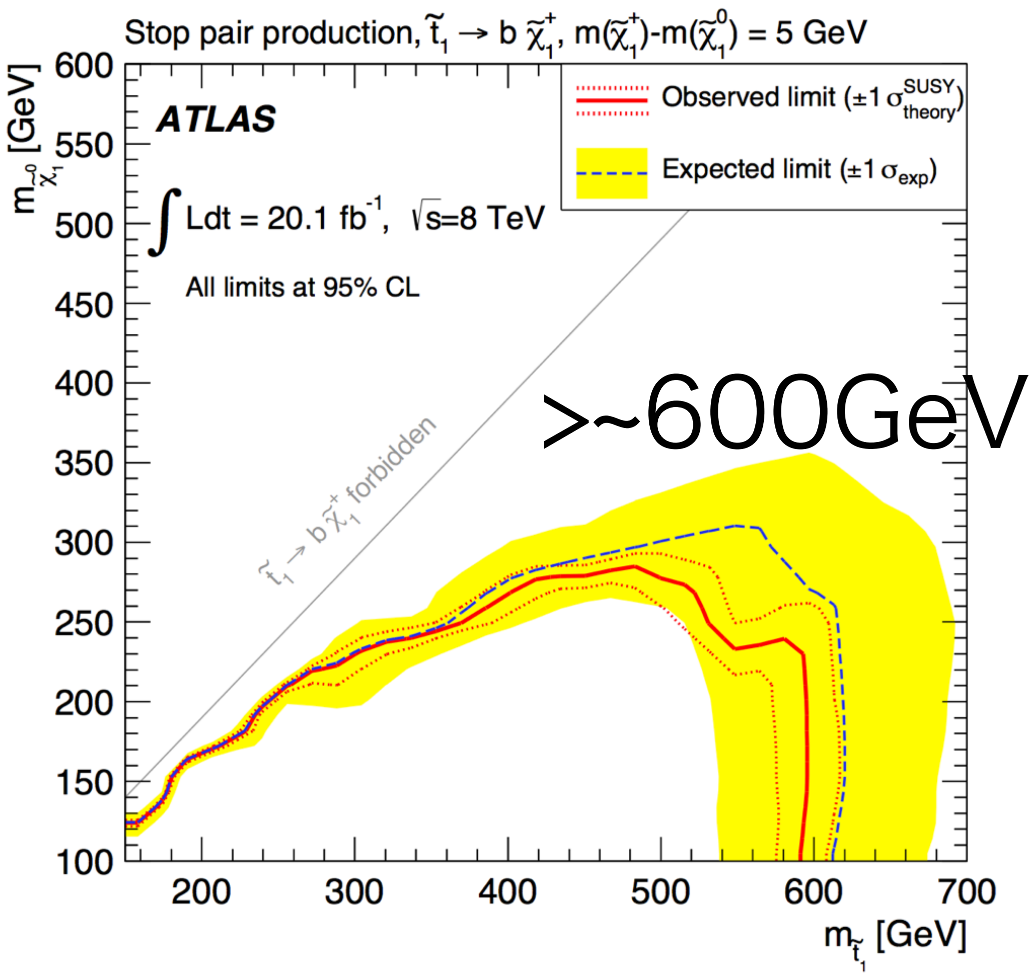
We can understand the EWSB scale via SUSY scale

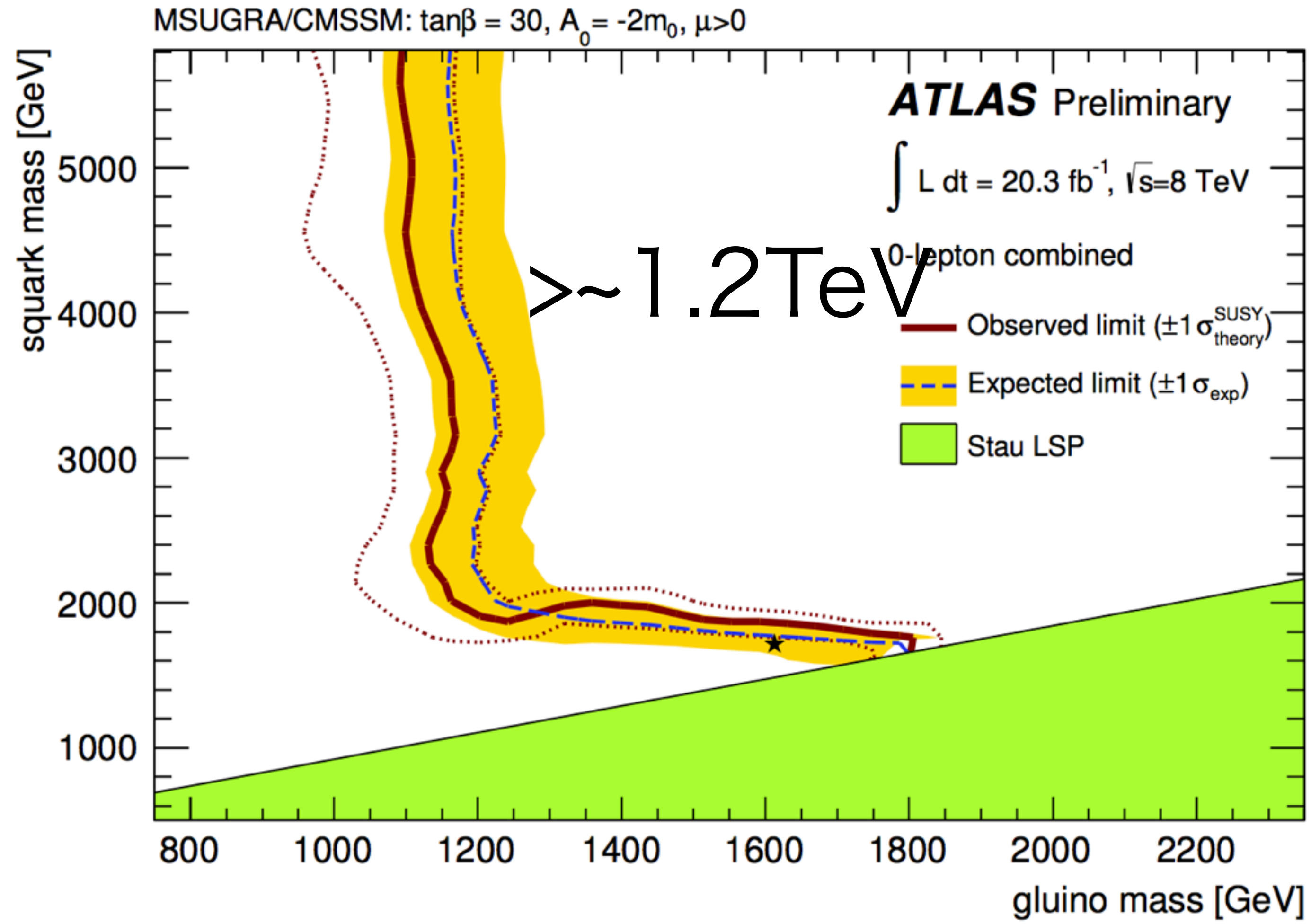
But

Non observation of SUSY particles

stop direct search

gluino/squark search



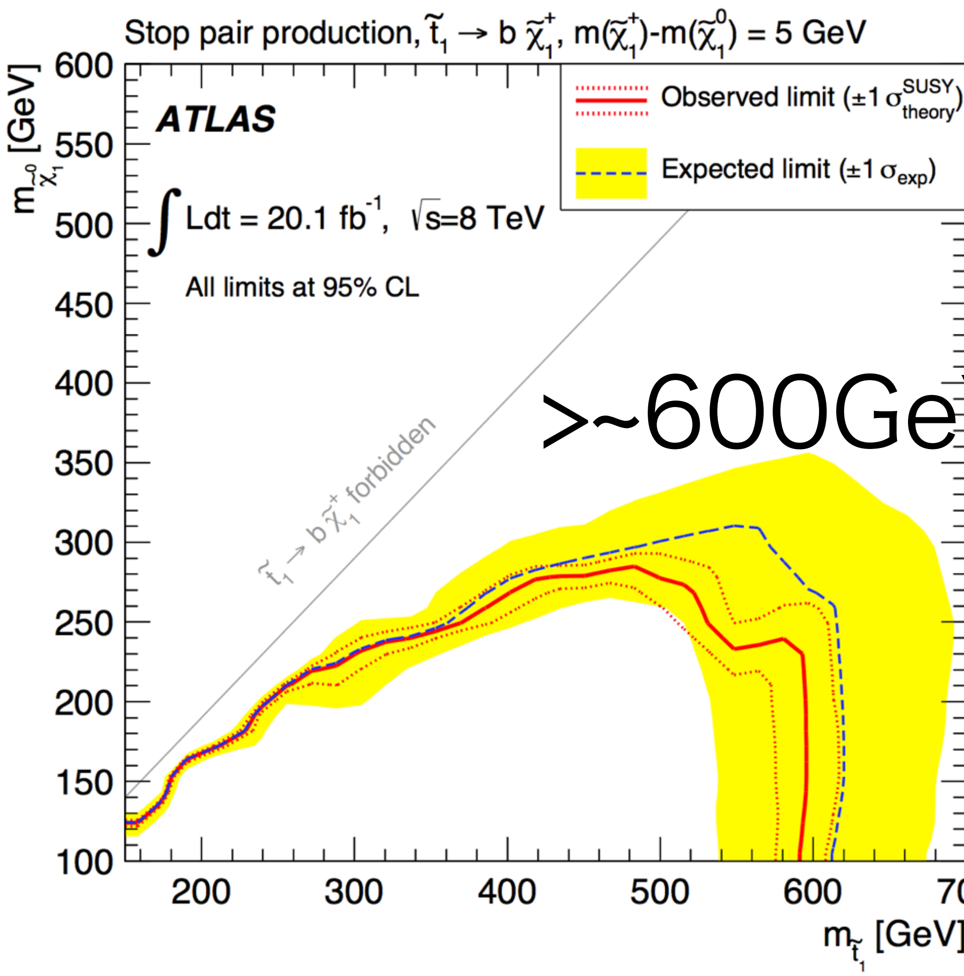


Larger SUSY scale → larger fine-tuning

We need to **reconsider** the fine-tuning problem

Non observation of SUSY particles

stop direct search



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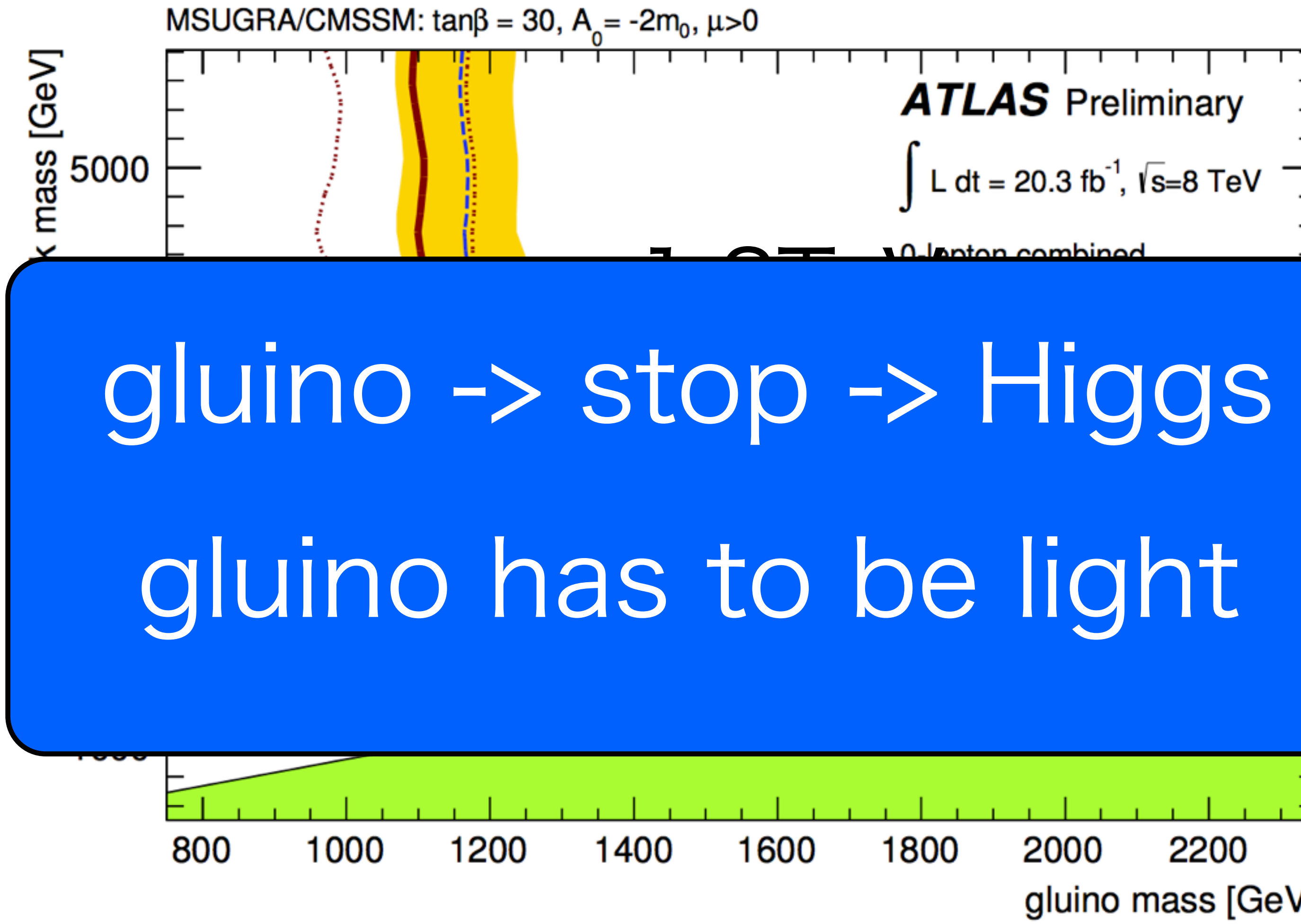


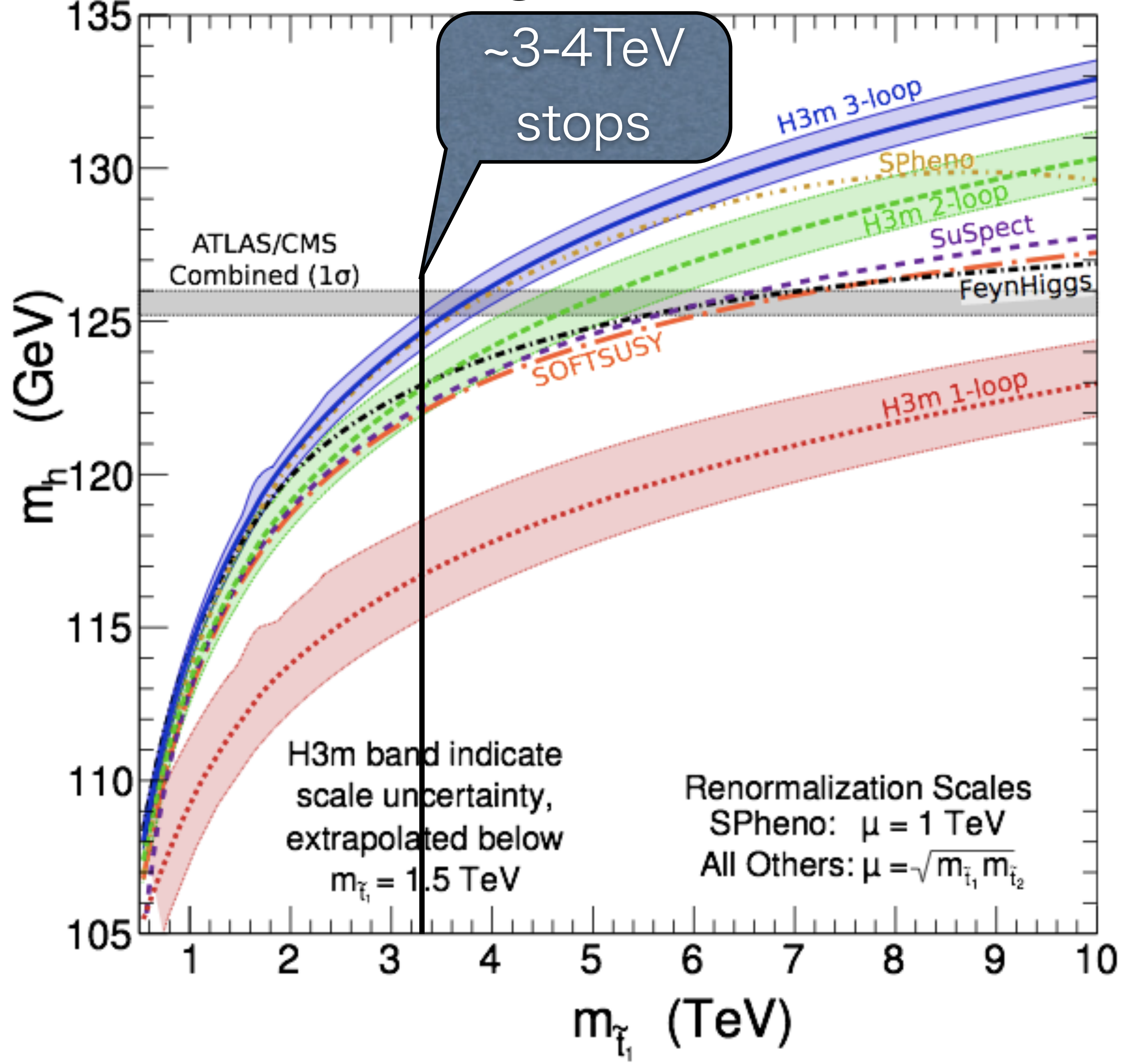
gluino -> stop -> Higgs

gluino has to be light

Larger SUSY scale → larger fine-tuning

We need to **reconsider** the fine-tuning problem

Moreover observed Higgs boson mass requires rather large radiative correction



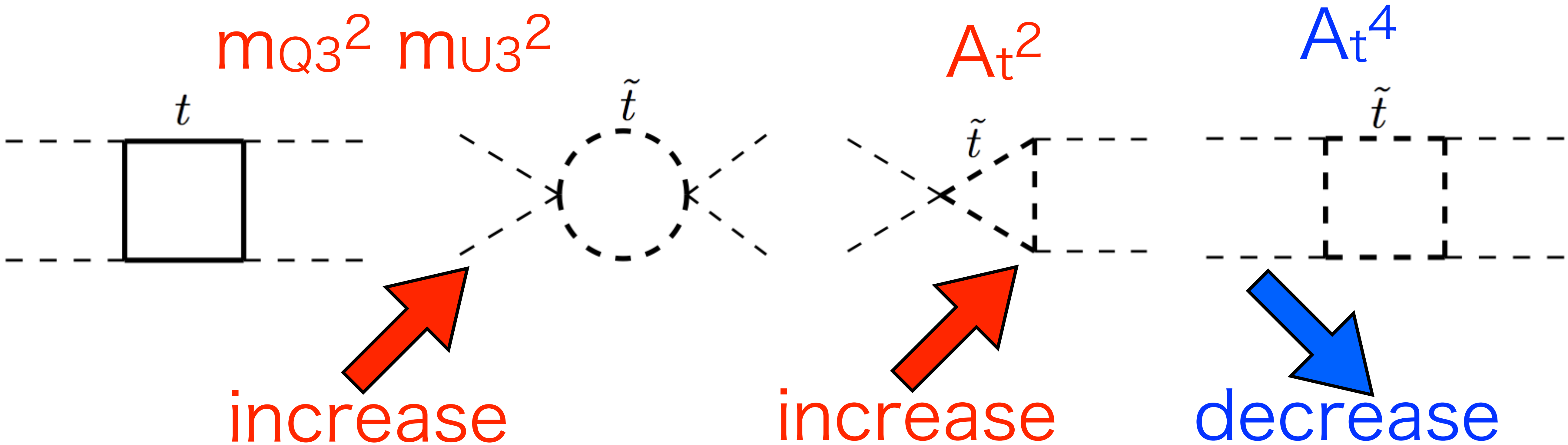
$O(\alpha_t \, \alpha_S^2)$

J.L. Feng, P. Kant, S. Profumo and D. Sanford, 1306.2318

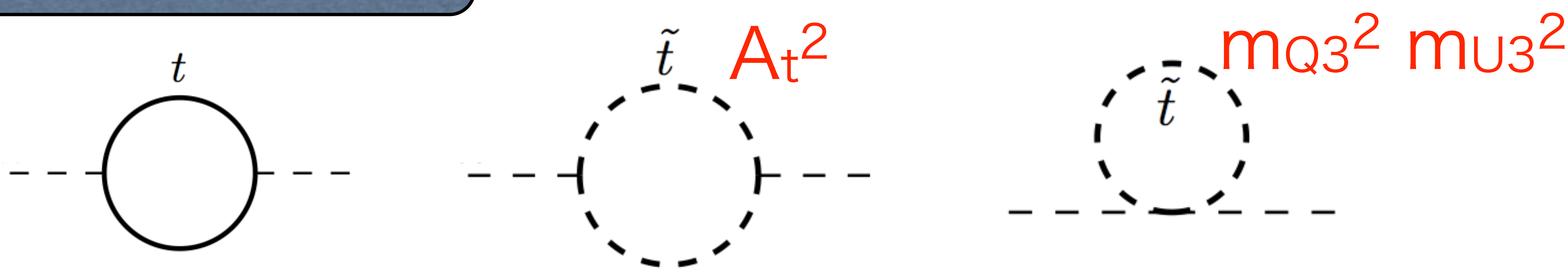
The H3m error corresponds to change of the renormalization scale from Ms/2 to 2Ms

Larger m_{Q3} m_{U3} A_t increase both Higgs boson mass and Higgs soft mass

Higgs mass



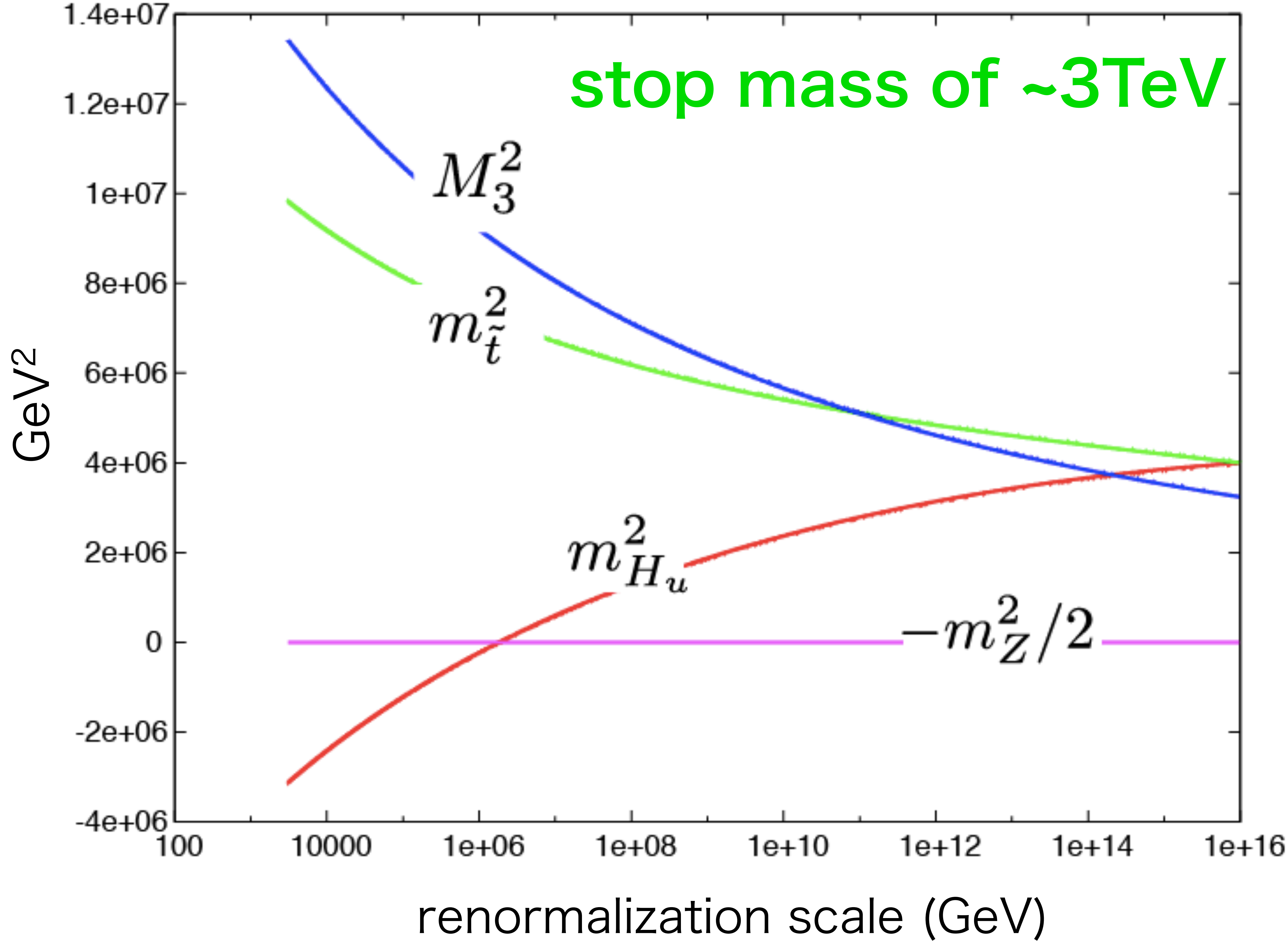
Higgs soft mass squared



+ wave function renormalization of H_u

Figures from "SUSY primer", S. Martin

We need an elaborate choice of μ-parameter



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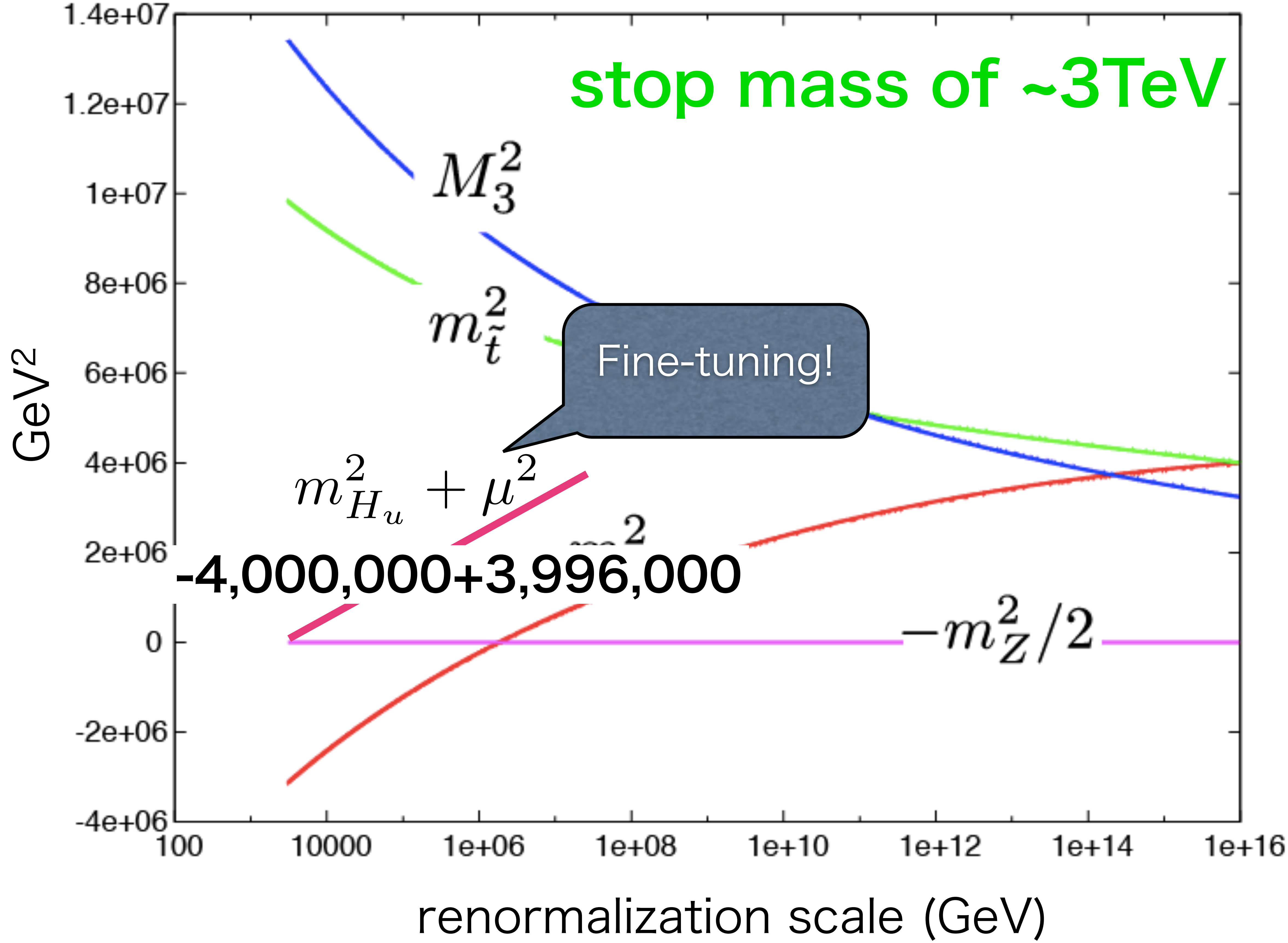

How can we understand the EWSB scale?

Approaches to the origin of the Fermi scale

- Low scale SUSY (and low messenger scale)

Attractive but difficult in the current situation

- Anthropic principle/never mind
(much better than the fine-tuning of the cosmological constant)

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- **Special relations among parameters at UV physics**

Approaches to the origin of the Fermi scale

- Low scale SUSY (and low messenger scale)

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- Anthropic principle/never mind
(much better than the fine-tuning of the cosmological constant)
- **Special relations among parameters at UV physics**

Focus point!

Original Focus Point

universal scalar mass $\qquad\qquad$ gaugino mass

$$m_0 \quad >> \quad M_{1/2}$$

Arises from minimal Kahler

input parameters at the GUT scale

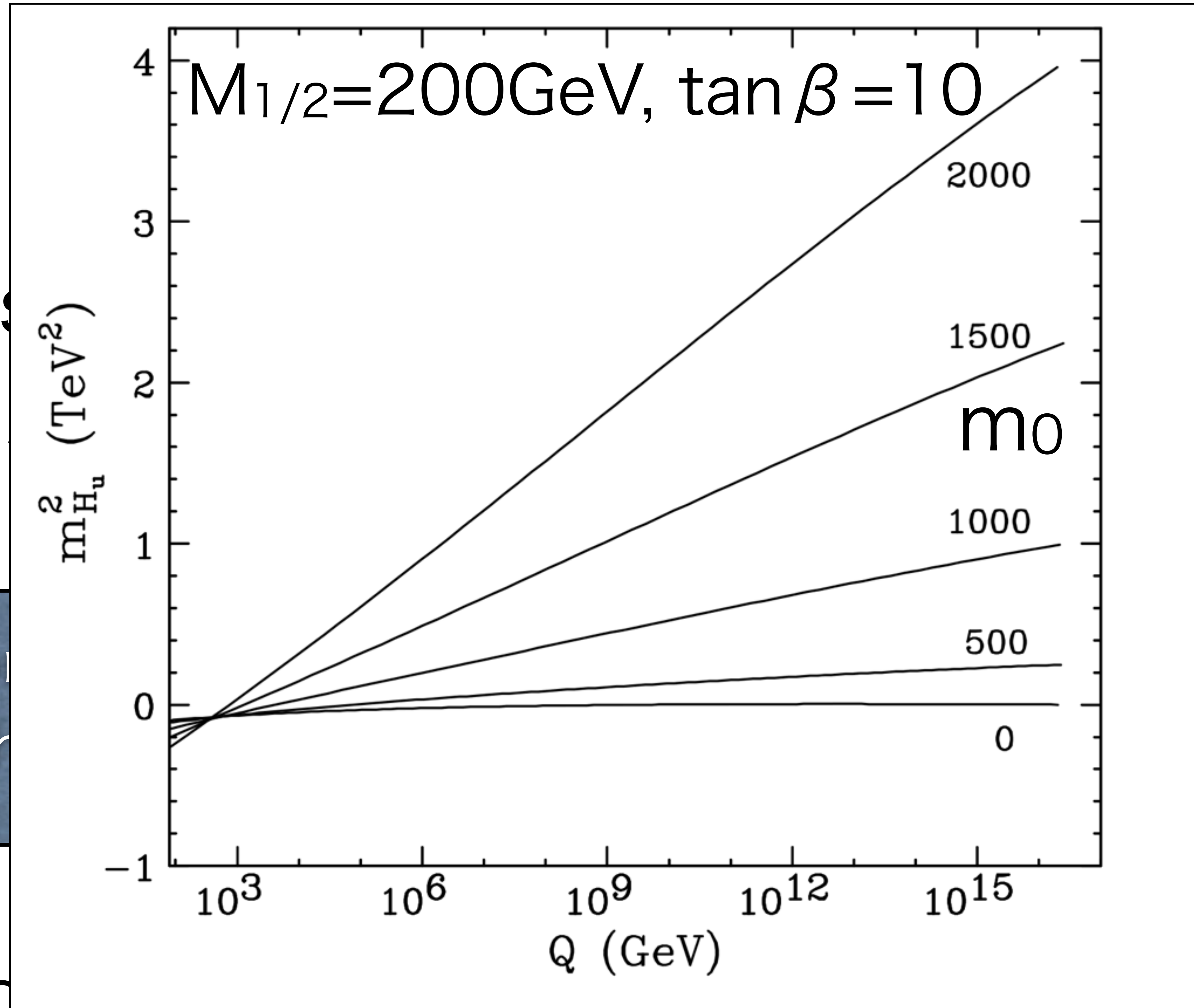
$m_{Hu}{}^2(m_Z)$ becomes much smaller than expected and does not sensitive to the change of m_0

[Feng, Matchev, Moroi, '99]

Orig

universal

Arises fro
minimal Kah



$m_{Hu}{}^2(m_Z)$ bec... cted
and does not sensitive to the change of m_0

[Feng, Matchev, Moroi, '99]

Why $m_{Hu}^2(m_{soft})$ is small ?

Why $m_{Hu}^2(m_{soft})$ is small ?

looks like coincidence

$$\frac{dm_{H_u}^2}{dt} \simeq \frac{1}{16\pi^2}[6Y_t^2(m_{Q_3}^2 + m_{H_u}^2 + m_{U_3}^2 + A_t^2) - 6g_2^2|M_2|^2 + \ldots]$$

$$\frac{dm_{U_3}^2}{dt} \simeq \frac{1}{16\pi^2}[4Y_t^2(m_{Q_3}^2 + m_{H_u}^2 + m_{U_3}^2 + A_t^2)$$

$$-(32/3)g_3^2 M_3^2 + \ldots]$$

$$\frac{dm_{Q_3}^2}{dt} \simeq \frac{1}{16\pi^2}[2Y_t^2(m_{Q_3}^2 + m_{H_u}^2 + m_{U_3}^2 + A_t^2)$$

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$$-(32/3)g_3^2M_3^2 - 6g_2^2M_2^2 + \ldots]$$

Taking $A_0=0$, $m_0^2=0$ and $M_1=M_2=M_3=M_{1/2}$

$$\bar{m}_{H_u}^2(Q = m_{\rm stop}) = -|c_H|M_{1/2}^2$$

$c_H \sim 1$

$$\bar{m}_{U_3}^2(Q = m_{\rm stop}) = +|c_u|M_{1/2}^2$$

$$\bar{m}_{Q_3}^2(Q = m_{\rm stop}) = +|c_Q|M_{1/2}^2$$

We want to make $M_{1/2}$ small

Let us shift boundary value $m_0=0$ to δm_0

$$m_{H_u}^2 \to m_{H_u}^2 + \delta m_{H_u}^2$$
$$m_{U_3}^2 \to m_{U_3}^2 + \delta m_{U_3}^2$$
$$m_{Q_3}^2 \to m_{Q_3}^2 + \delta m_{Q_3}^2$$

RGEs for A_t, M_1, M_2, M_3 do not change

(because of the mass dimension)

A_t, M_1, M_2, M_3 do not change

RGEs for δm_{Hu}^2, δm_{U3}^2, δm_{Q3}^2

$$\frac{d}{dt}\begin{bmatrix}\delta m_{H_u}^2\\ \delta m_{U_3}^2\\ \delta m_{Q_3}^2\end{bmatrix} = \frac{Y_t^2}{8\pi^2}\begin{bmatrix}3&3&3\\2&2&2\\1&1&1\end{bmatrix}\begin{bmatrix}\delta m_{H_u}^2\\ \delta m_{U_3}^2\\ \delta m_{Q_3}^2\end{bmatrix}$$

solving RGEs

$$\begin{bmatrix}\delta m_{H_u}^2(Q)\\ \delta m_{U_3}^2(Q)\\ \delta m_{Q_3}^2(Q)\end{bmatrix} = \frac{\delta m_0^2}{2}\left\{\begin{bmatrix}3\\2\\1\end{bmatrix}\exp\left[\int_0^t \frac{6Y_t^2(t')}{8\pi^2}dt'\right] - \begin{bmatrix}1\\0\\-1\end{bmatrix}\right\}$$

$$t = \ln(M_{\rm GUT}/Q)$$

RGEs for $\delta m_{H_u}^2$, $\delta m_{U_3}^2$, $\delta m_{Q_3}^2$

$$\frac{d}{dt}\begin{bmatrix}\delta m_{H_u}^2\\ \delta m_{U_3}^2\\ \delta m_{Q_3}^2\end{bmatrix} = \frac{Y_t^2}{8\pi^2}\begin{bmatrix}3&3&3\\2&2&2\\1&1&1\end{bmatrix}\begin{bmatrix}\delta m_{H_u}^2\\ \delta m_{U_3}^2\\ \delta m_{Q_3}^2\end{bmatrix}$$

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$$t = \ln(M_{\rm GUT}/Q)$$

This factor is accidentally ~1/3 !

for Q~M_Z, M_{GUT}~10^{16}GeV, Y_t~1

Then $\delta m_{H_u}^2 \sim 0$

RGEs for δm_{Hu}^2, δm_{U3}^2, δm_{Q3}^2

$$\frac{d}{dt}\begin{bmatrix}\delta m_{H_u}^2\\ \delta m_{U_3}^2\\ \delta m_{Q_3}^2\end{bmatrix} = \frac{Y_t^2}{8\pi^2}\begin{bmatrix}3 & 3 & 3\\ 2 & 2 & 2\\ 1 & 1 & 1\end{bmatrix}\begin{bmatrix}\delta m_{H_u}^2\\ \delta m_{U_3}^2\\ \delta m_{Q_3}^2\end{bmatrix}$$

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This factor is ac

for Q~MZ, MGUT

Then $\delta\ldots$

RGEs for δm_{Hu}^2, δm_{U3}^2, δm_{Q3}^2

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Deep reason may be hidden

flavor symmetry breaking scale ↔ Y_t M_{GUT} ← Λ

(more fundamental physics)

Fine-tuning measure

Defining a fine-tuning measure

$$\Delta_a = \left| \frac{\partial \ln m_{\hat{Z}}}{\partial \ln a} \right|_{m_{\hat{Z}} = m_Z} \qquad \boxed{\Delta = \max(\Delta_a)}$$

a is a fundamental parameter

J. R. Ellis, K. Enqvist, D. V. Nanopoulos and F. Zwirner, Mod. Phys. Lett. A **1**, 57 (1986); R. Barbieri and G. F. Giudice, Nucl. Phys. B **306**, 63 (1988).

e.g., mSUGRA

$$\{a_i\} = \{m_0, M_{1/2}, \mu_0, A_0, B_0\}$$

$$\Delta_{B_0} \sim (1/\tan\beta)\Delta_{\mu_0}$$

(can be neglected for large $\tan\beta$)

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e.g., mSUGRA

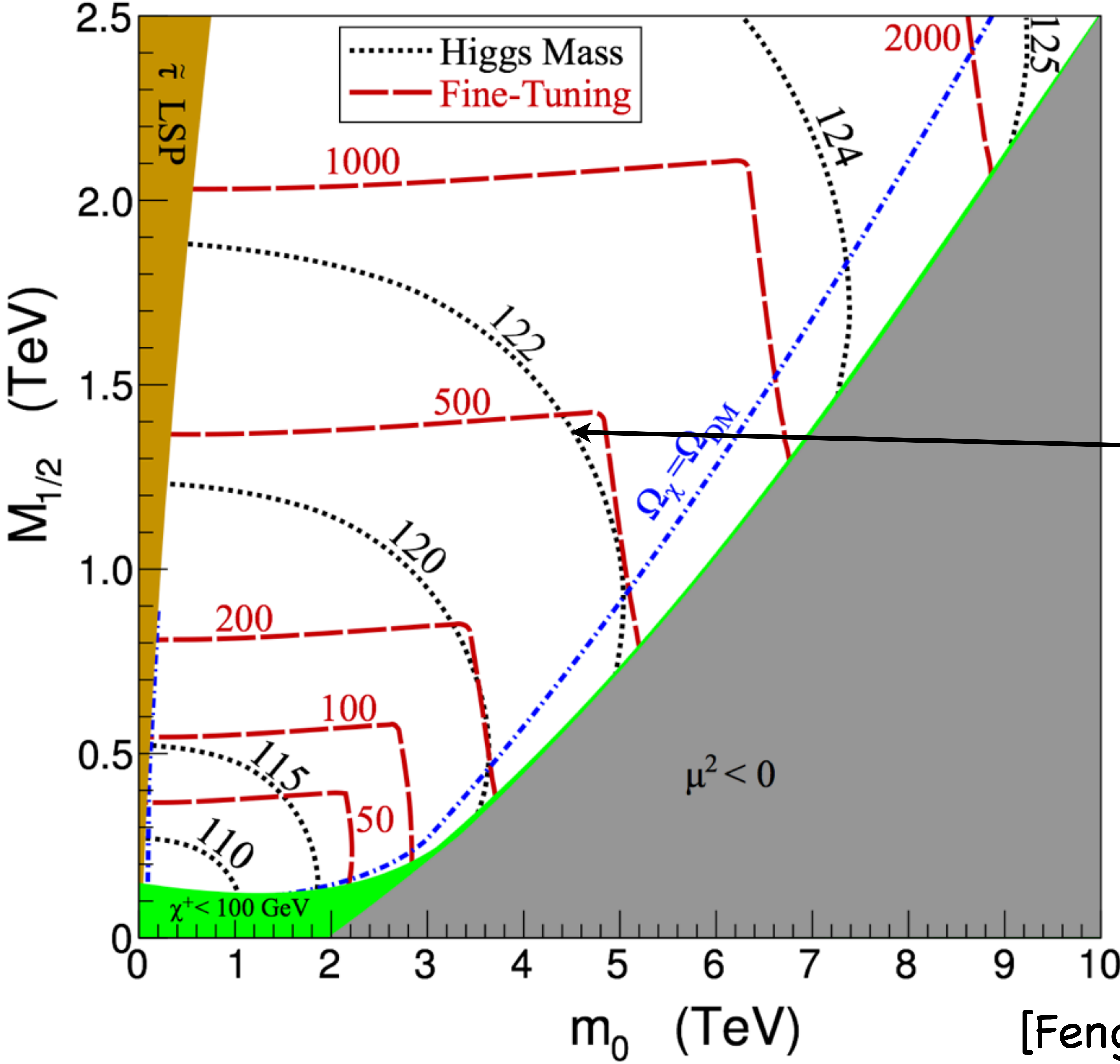
$$\{a_i\} = \{m_0, M_{1/2}, \mu_0, A_0, B_0\}$$

$$(\Delta_{\mu_0})^{-1} = \frac{m_Z^2}{\mu_0^2} \left(\frac{dm_Z^2}{d\mu^0} \right)^{-1} \sim \frac{m_Z^2}{2\mu^2}$$

Δ_{μ_0}

ge tan β)

Without A-term



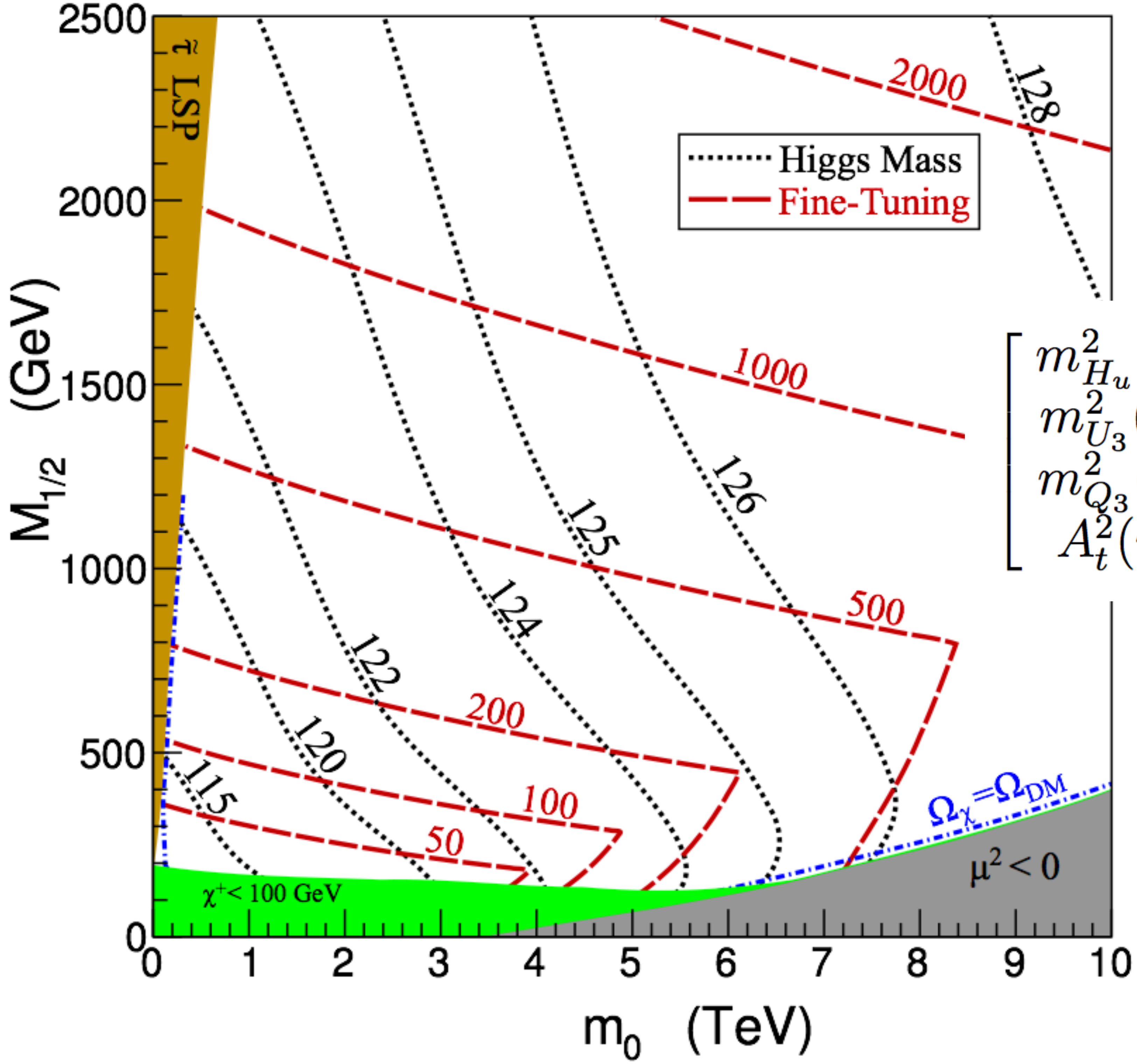
122 can be consistent with observed value

Δ~500

(Higgs mass is calculated using SoftSUSY, tan β=10, A_0=0)

[Feng, Sanford, 2012]

With A-term



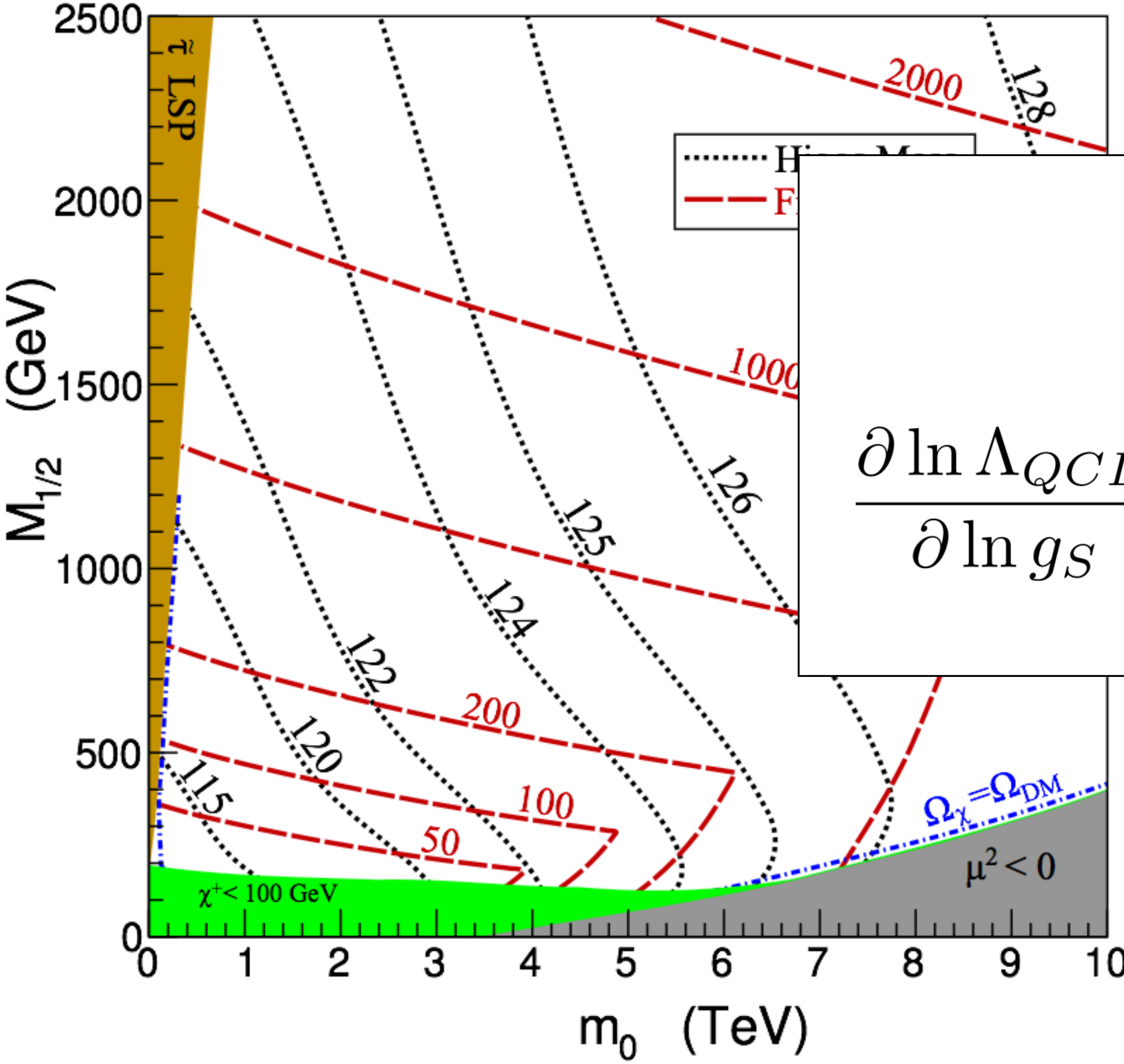
$$\begin{bmatrix} m_{H_u}^2(m_{\rm GUT}) \\ m_{U_3}^2(m_{\rm GUT}) \\ m_{Q_3}^2(m_{\rm GUT}) \\ A_t^2(m_{\rm GUT}) \end{bmatrix} = m_0^2 \begin{bmatrix} 1 \\ 1+x-3y \\ 1-x \\ 9y \end{bmatrix}$$

$$(x, y) = \left(\frac{1}{4}, \frac{1}{6}\right)$$

(Higgs mass is calculated using SoftSUSY, $\tan\beta = 10$)

Fine-tuning is reduced to Δ~50-100

With A-term



QCD

$$\left.\frac{\partial \ln \Lambda_{QCD}}{\partial \ln g_S}\right|_{\mathrm{M_{GUT}}} \sim \frac{4\pi}{b\alpha_S} \sim 50$$

$(x, y) = (\frac{\ }{4}, \frac{\ }{6})$

(Higgs mass is calculated using SoftSUSY, $\tan\beta = 10$)

Fine-tuning is reduced to $\Delta \sim 50\text{-}100$

In the original focus point, the gaugino masses are taken to be **small** and **universal**

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Let us look into gaugino contributions more closely for **larger** gaugino masses

GUT scale parameters

$$m_{H_u}^2(2.5\,\mathrm{TeV}) \simeq -1.197M_3^2 + 0.235M_2^2 - 0.013M_1M_3 - 0.134M_2M_3 + 0.010M_1^2 - 0.027M_1M_2 + 0.067m_0^2,$$

~m_{stop}

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~m_{stop}

Gaugino contributions to m_{Hu}^2 become small with certain ratios of gaugino masses

[G.L. Kane and S.F. King, '98; H. Abe, T. Kobayashi and Y. Omura, '07; S. P. Martin, '07; Horton and Ross '09]

We proposed

"Focus point gaugino mediation"

[Yanagida, Yokozaki '13]

[Kaminska, Ross, Schmidt-Hoberg '13]

We proposed

"Focus point gaugino mediation"

[Yanagida, Yokozaki '13]

[Kaminska, Ross, Schmidt-Hoberg '13]

M_3/M_2

Very simple

Only one parameter determines
the focus-point behavior

Bino mass is not so important, unless it is very large

We proposed
"Focus point gaugino mediation"

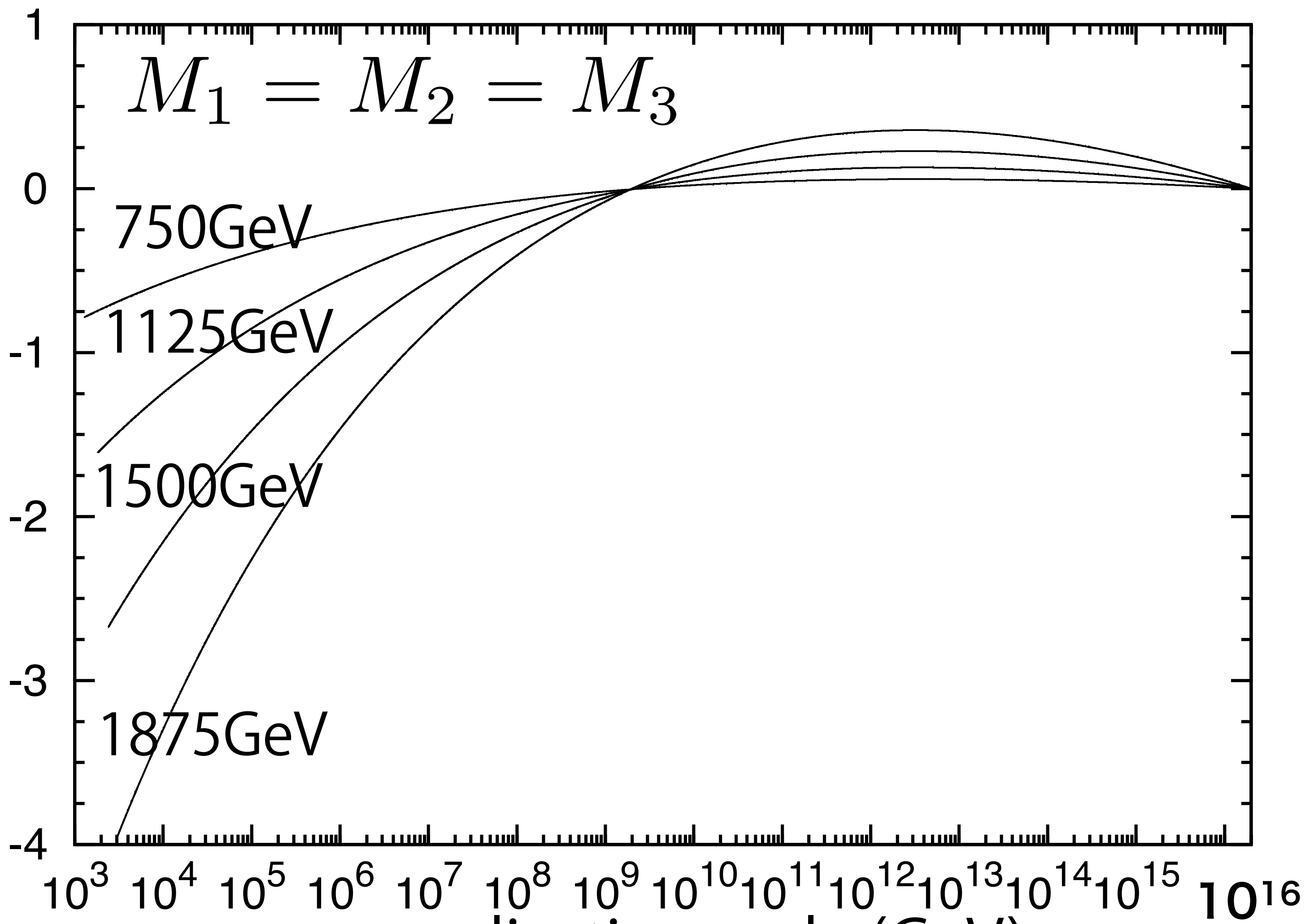
[Yanagida, Yokozaki '13]
[Kaminska, Ross, Schmidt-Hoberg '13]

The fixed ratio of the gluino mass to wino mass M_2/M_3~0.4, e.g., 3/8 reduces fine-tuning significantly

$$m_{H_u}^2(2.5\mathrm{TeV}) \simeq \underline{-0.006 M_{1/2}^2} \text{ for } r_1 = r_3 = 8/3$$

where $(M_1, M_2, M_3) = (r_1, 1, r_3) M_{1/2}$.

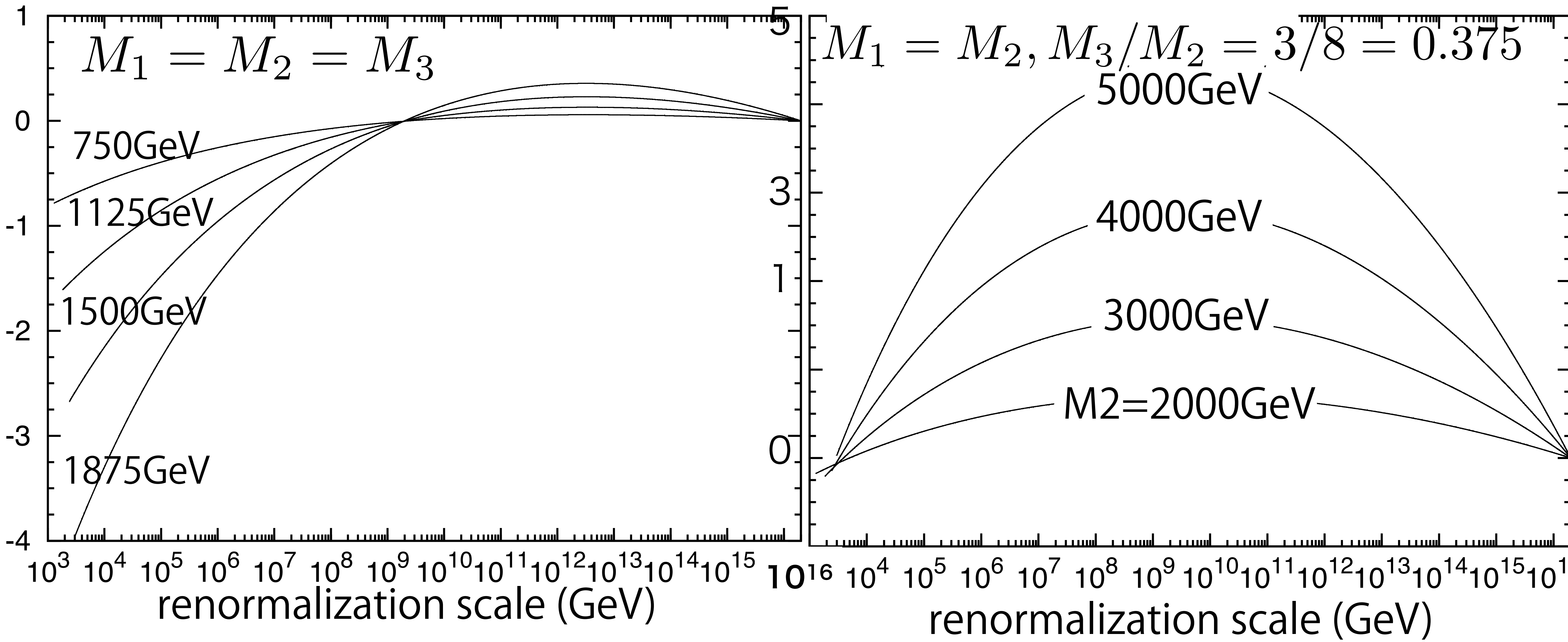
The running of m_{Hu}^2 (TeV^2)



universal case

For almost same gluino mass

The running of m_{Hu}^2 (TeV^2)



universal case

M_2:M_3=8:3 case

For almost same gluino mass

Higgs boson mass @ three loop level

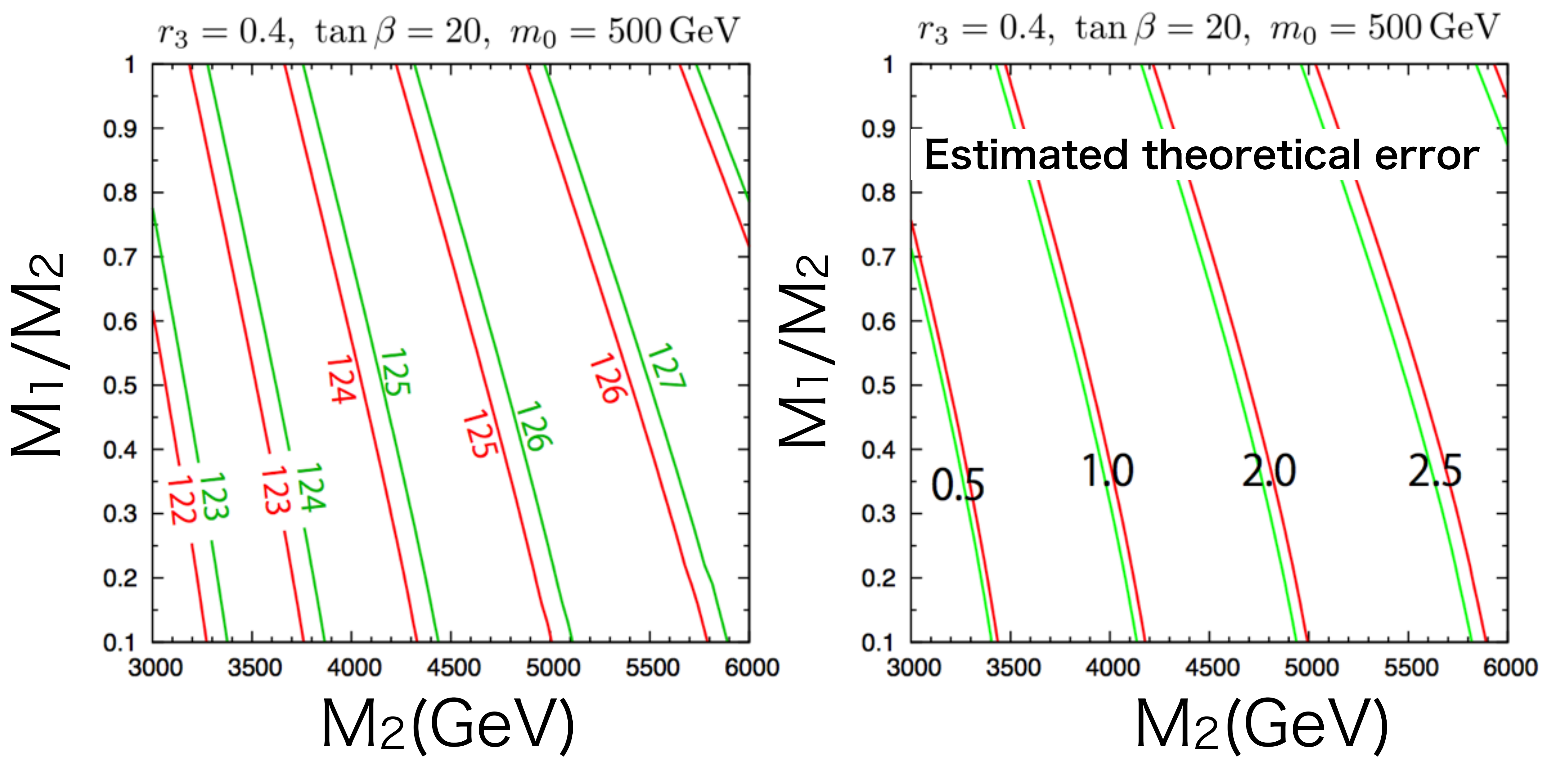
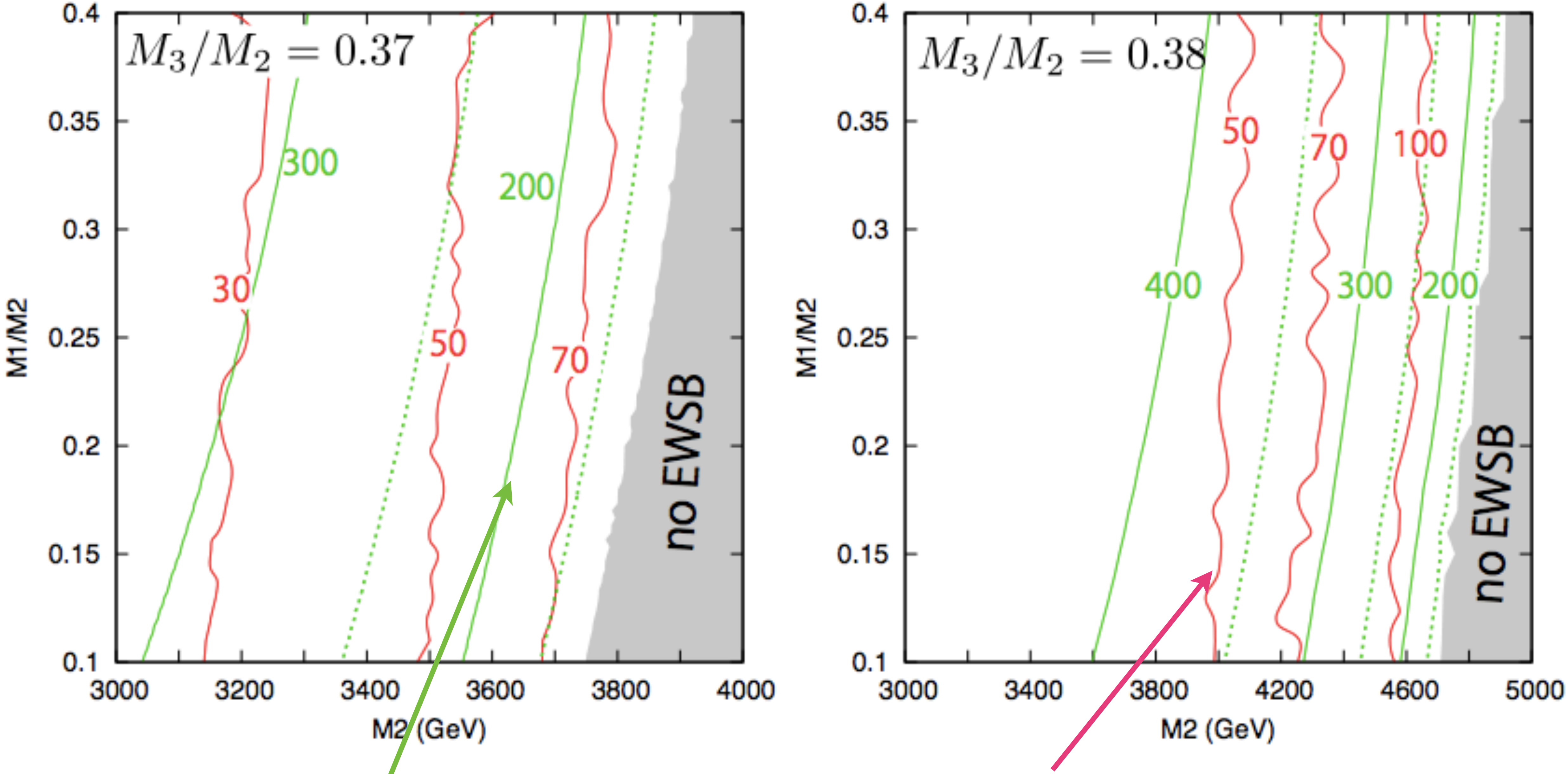


Figure 2: Contours of the Higgs boson mass (left panel) and Δm_h (right panel) in the unit of GeV. The red (green) lines drawn with the top mass of $m_t = 173.2$ GeV (174.2 GeV). Here, $\alpha_S(m_Z) = 0.1184$.

red: m_t=173.2 GeV green: m_t=174.2 GeV

Fine-tuning and Higgsino mass



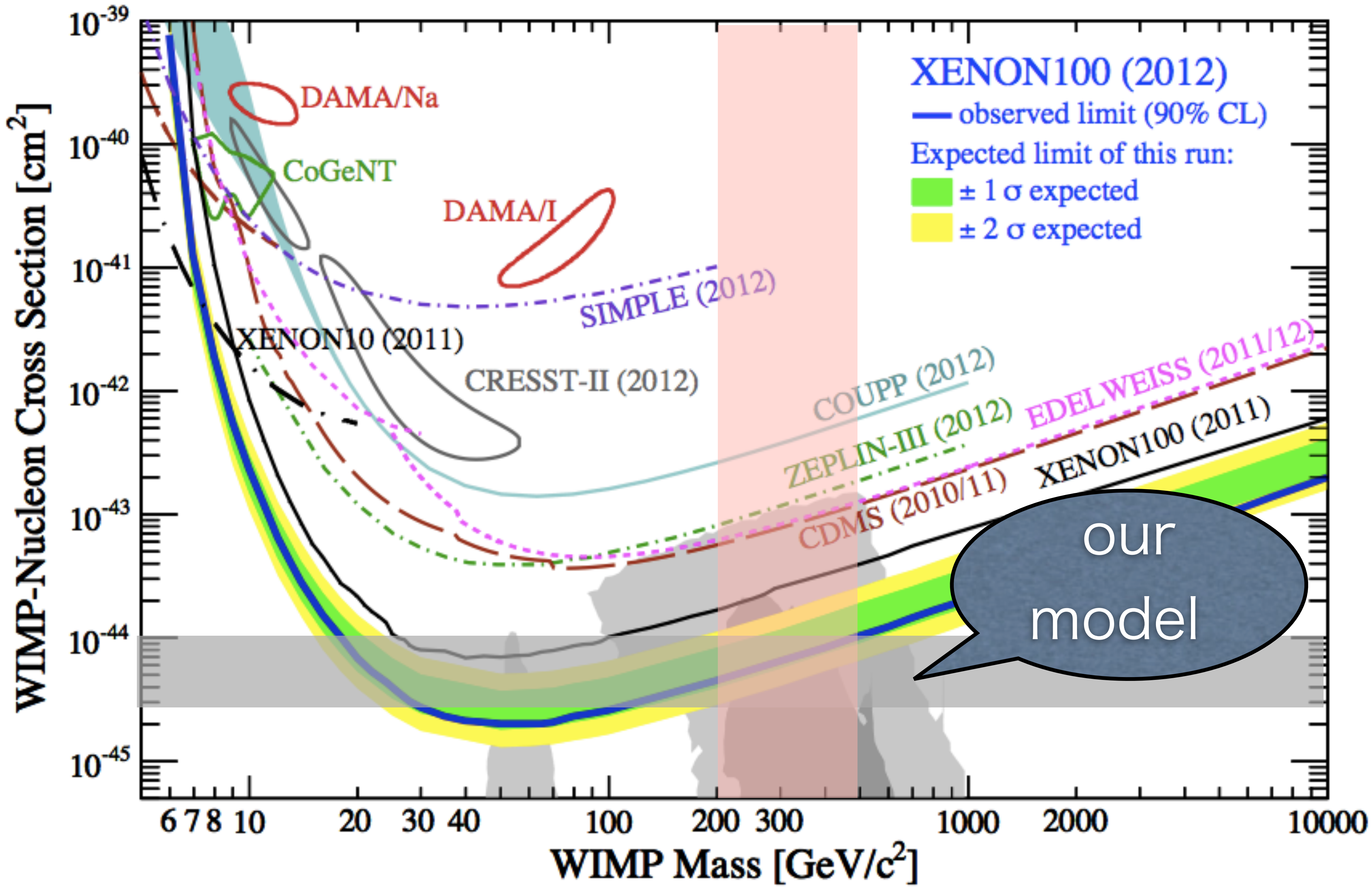
Higgsino mass μ 　 Δ (fine-tuning measure)

$$\Delta = \mathrm{Max}\left[\left| \frac{\partial \ln m_{\hat{Z}}}{\partial \ln M_2(M_{\mathrm{GUT}})} \right|_{m_{\hat{Z}}=m_Z}, \left| \frac{\partial \ln m_{\hat{Z}}}{\partial \ln \mu^0} \right|_{m_{\hat{Z}}=m_Z} \right]$$

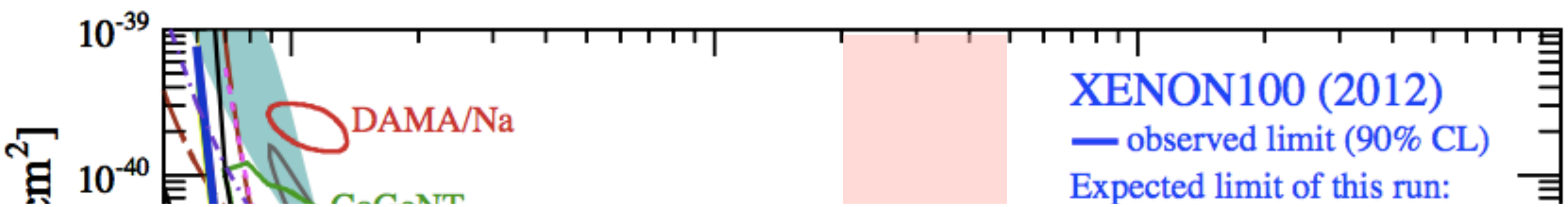
Predictions

- At least Higgsino is light, which can be target at the ILC
- Neutralino can be dark matter
- Gravitino can also be dark matter

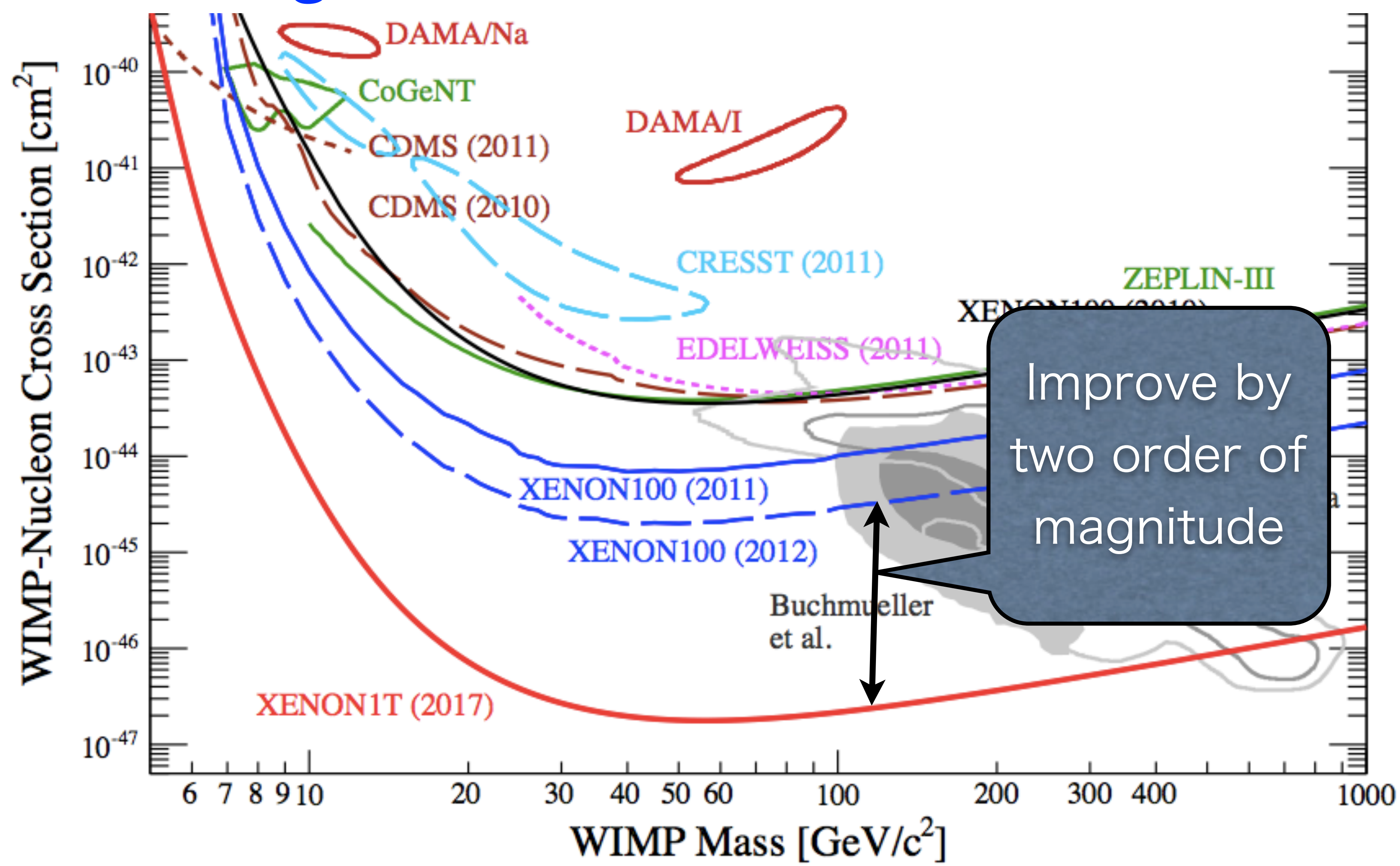
Predictions



Predictions



Whole region will be covered at XENON 1T



The origin of 8:3

- May be determined by dim(SU(2)$_{\text{adj}}$): dim(SU(3)$_{\text{adj}}$)

Wino $M_2 = M_5/\dim(SU(2)_{\rm adj})$

Gluino $M_3 = M_5/\dim(SU(3)_{\rm adj})$

The origin of 8:3

- May be determined by dim(SU(2)$_{\text{adj}}$): dim(SU(3)$_{\text{adj}}$)

Wino $M_2 = M_5/\dim(SU(2)_{\text{adj}})$

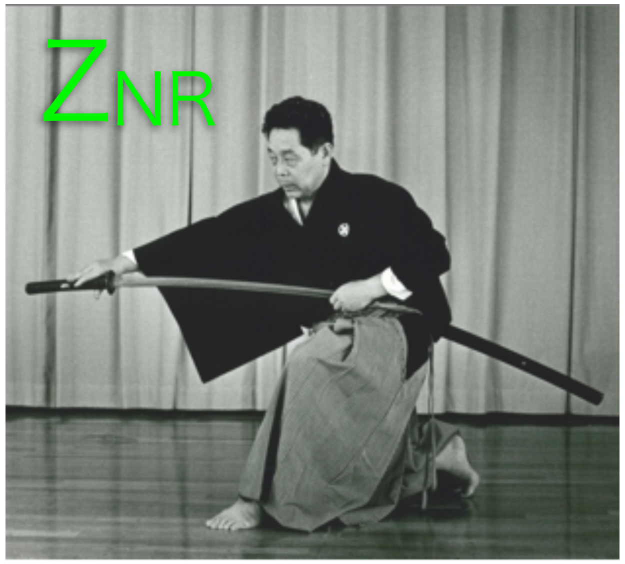
Gluino $M_3 = M_5/\dim(SU(3)_{\text{adj}})$

- **Anomaly free condition of Z_{NR}**

Suppose that there exist non-anomalous discrete R-symmetry

$$W \ni \frac{QQQL}{M_P}, \frac{\bar{U}\bar{U}\bar{D}\bar{E}}{M_P}$$

proton decay operators



Let us focus on even number of N

Z_{4R}, Z_{6R}, Z_{8R} ...

For N=even, constant term breaks Z_{NR} to R-parity

(For N=odd, R-Parity is broken by constant term)

μ-term is generated by Giudice Masiero mechanism

Forbid bare Hu Hd

$$r_u + r_d = 0 \mod N \text{ (and } r_u + r_d \neq 2).$$

$$\mathbf{A}_2 = 2 \mod N, \quad \mathbf{A}_3 = 6 \mod N.$$

Z_{NR}-SU(2)$_L$-SU(2)$_L$ Z_{NR}-SU(3)$_C$-SU(3)$_C$

Z_{NR} transformation

$$\mathrm{Im}(Z/M_*) \to \mathrm{Im}(Z/M_*) + (2\pi l'/N)$$
$$\psi_i \to \psi_i \exp\left[i(r_i - 1)(2\pi l'/N)\right)$$

r_i: charge of matter fermion and Higgsino

$$\frac{k_2}{32\pi^2}\int d^2\theta \frac{Z}{M_*}(W^a_\alpha)_2(W^{a\,\alpha})_2,$$ wino mass

$$\frac{k_3}{32\pi^2}\int d^2\theta \frac{Z}{M_*}(W^a_\alpha)_3(W^{a\,\alpha})_3,$$ gluino mass

conjecture

Shift of Im(Z/M*) cancels the anomaly

$$\mathbf{A}_2 = 2 \bmod N, \quad \mathbf{A}_3 = 6 \bmod N.$$

$$A_2 = 2 + k_2 \bmod N, \quad A_3 = 6 + k_3 \bmod N$$

Anomaly cancellation: $A_2 = A_3 = 0 \bmod N$

$k_2=16$, $k_3=6$ for Z_{6R}

$$\frac{k_2}{32\pi^2}\int d^2\theta \frac{Z}{M_*}(W^a_\alpha)_2(W^{a\,\alpha})_2,$$

$$\frac{k_3}{32\pi^2}\int d^2\theta \frac{Z}{M_*}(W^a_\alpha)_3(W^{a\,\alpha})_3,$$

$M_{wino} : M_{gluino} = 8 : 3$

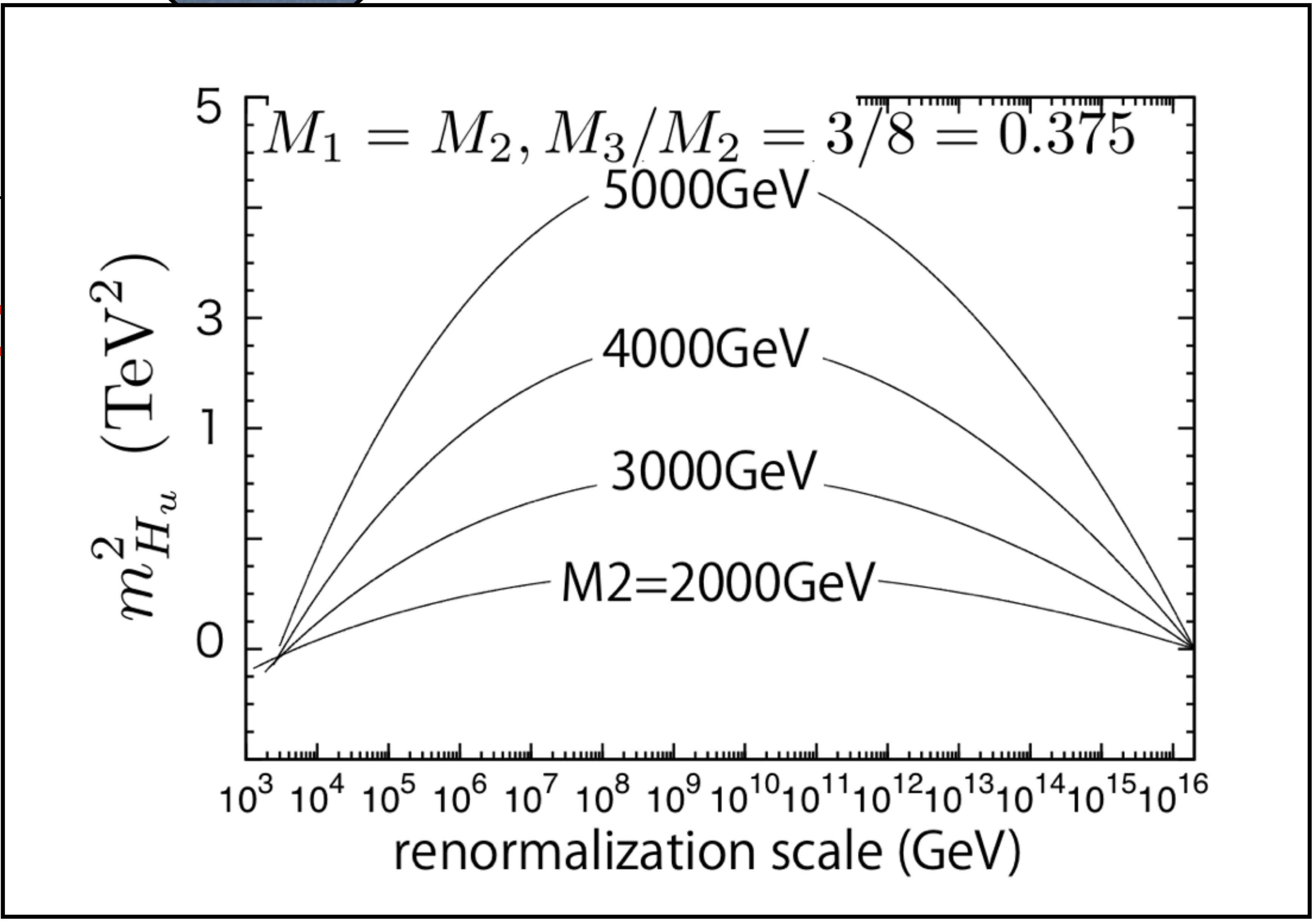
(No solution with $k_2/k_3=8/3$ for Z_{4R})

$$\mathbf{A}_2 = 2 \bmod N, \quad \mathbf{A}_3 = 6 \bmod N.$$

$A_2 = 2 + k_2$ m

Anomaly canc

k2=



M_{wino} : M_{gluino} = 8 : 3

(No solution with k_2/k_3=8/3 for Z_{4R})

Second Part

A GMSB model for explaining the muon g-2

Muon g-2 anomaly

If the muon g-2 anomaly is indeed true,
this is an important probe of the NP beyond SM

$$V(\vec{x}) = -\vec{\mu} \cdot \vec{B}(\vec{x})$$

$$\vec{\mu} = g\left(\frac{e}{2m_\mu}\right)\vec{S}$$

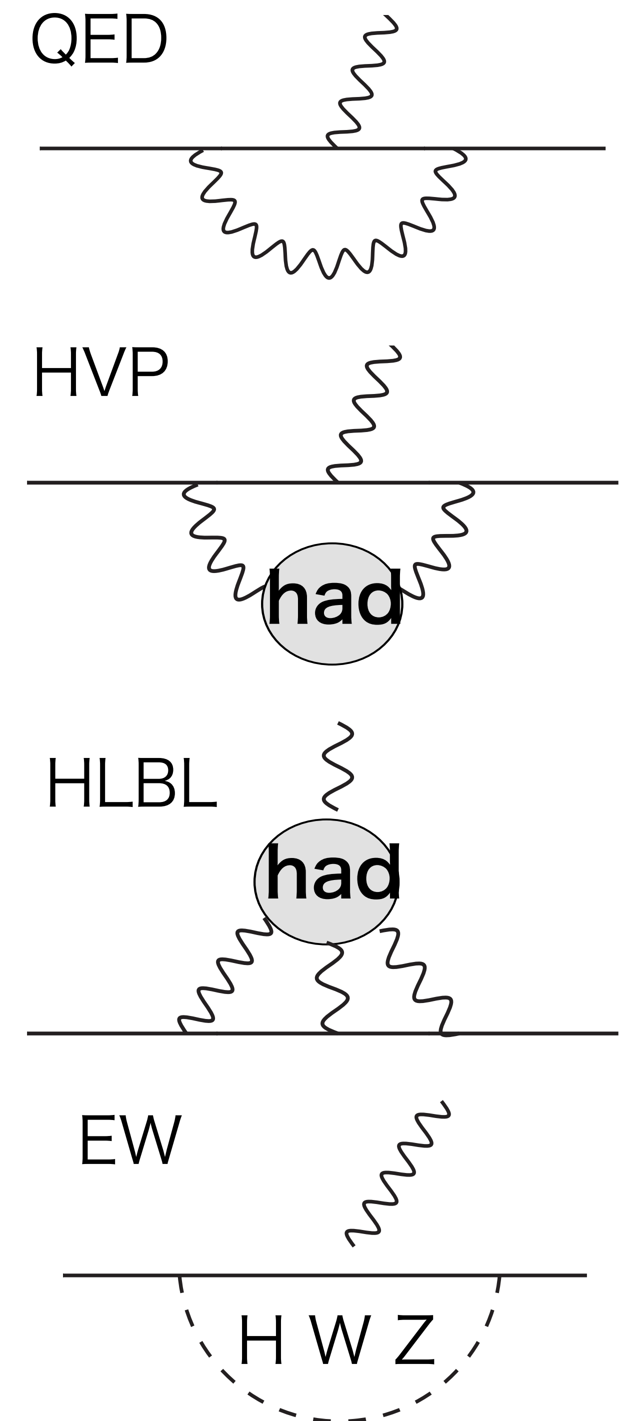
$$a_\mu = \frac{g-2}{2}$$

>3σ deviation from SM prediction!

SM prediction of the muon g-2

[10^{10}]

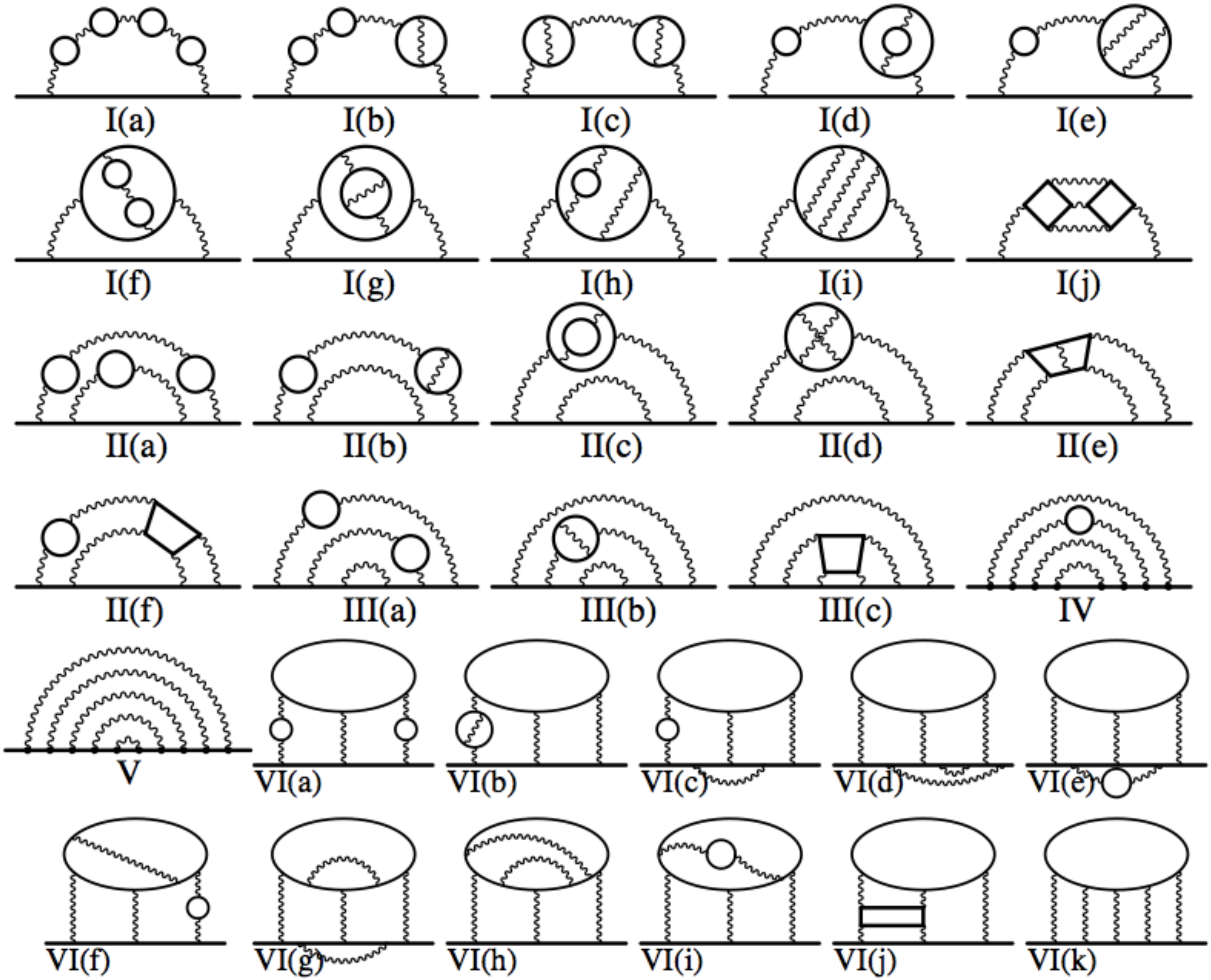
Experiment	11659208.9±6.3
QED@5loop	11658471.8951(80)
Hadronic vacuum polarization	LO: 694.91±4.27 [Hagiwara, Liao, Martin, Nomura, Teubner] LO: 692.3±4.2 [Davier, Hoecker, Malaescu, Zhang] HO: -9.84±0.07
Hadronic LBL	10.5±2.6
Electroweak@2loop	15.4±0.2



$$a_\mu^{\mathrm{EXP}} - a_\mu^{\mathrm{SM}} = \begin{array}{l} (26.1 \pm 8.0) \cdot 10^{-10} \\ (28.7 \pm 8.0) \cdot 10^{-10} \end{array}$$

[HLMT]
[DHMZ]

>3σ



[Aoyama, Hayakawa, Kinoshita, Nio '12]

SM prediction of the muon g-2

$[10^{10}]$

Experiment	11659208.9±6.3
QED@5loop	11658471.8951(80)
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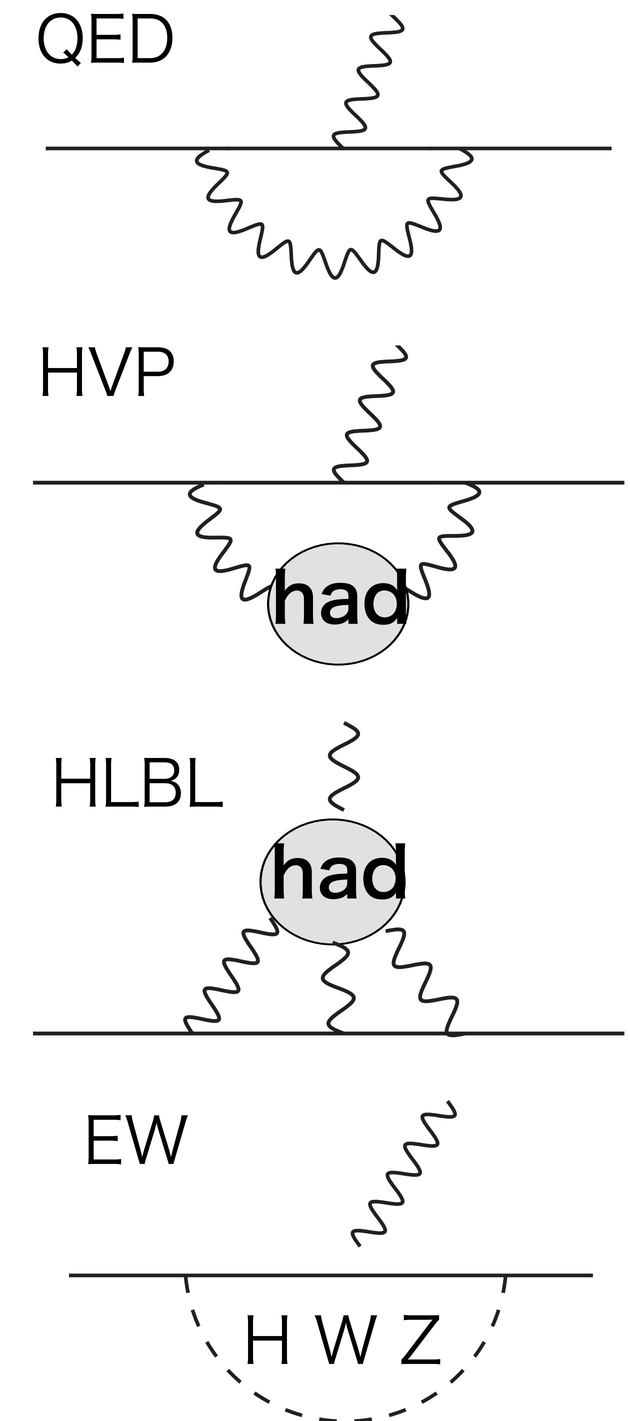
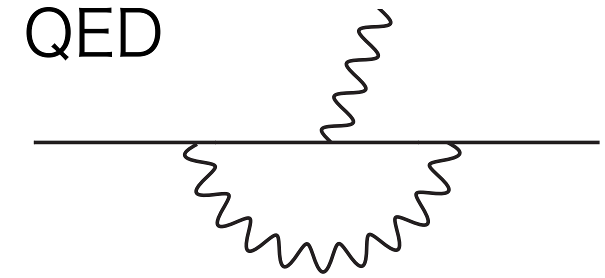


$$a_\mu^{\rm EXP} - a_\mu^{\rm SM} = \begin{array}{l} (26.1 \pm 8.0) \cdot 10^{-10} \ \text{[HLMT]} \\ (28.7 \pm 8.0) \cdot 10^{-10} \ \text{[DHMZ]} \end{array}$$

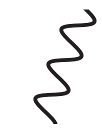
>3σ

SM prediction of the muon g-2

QED

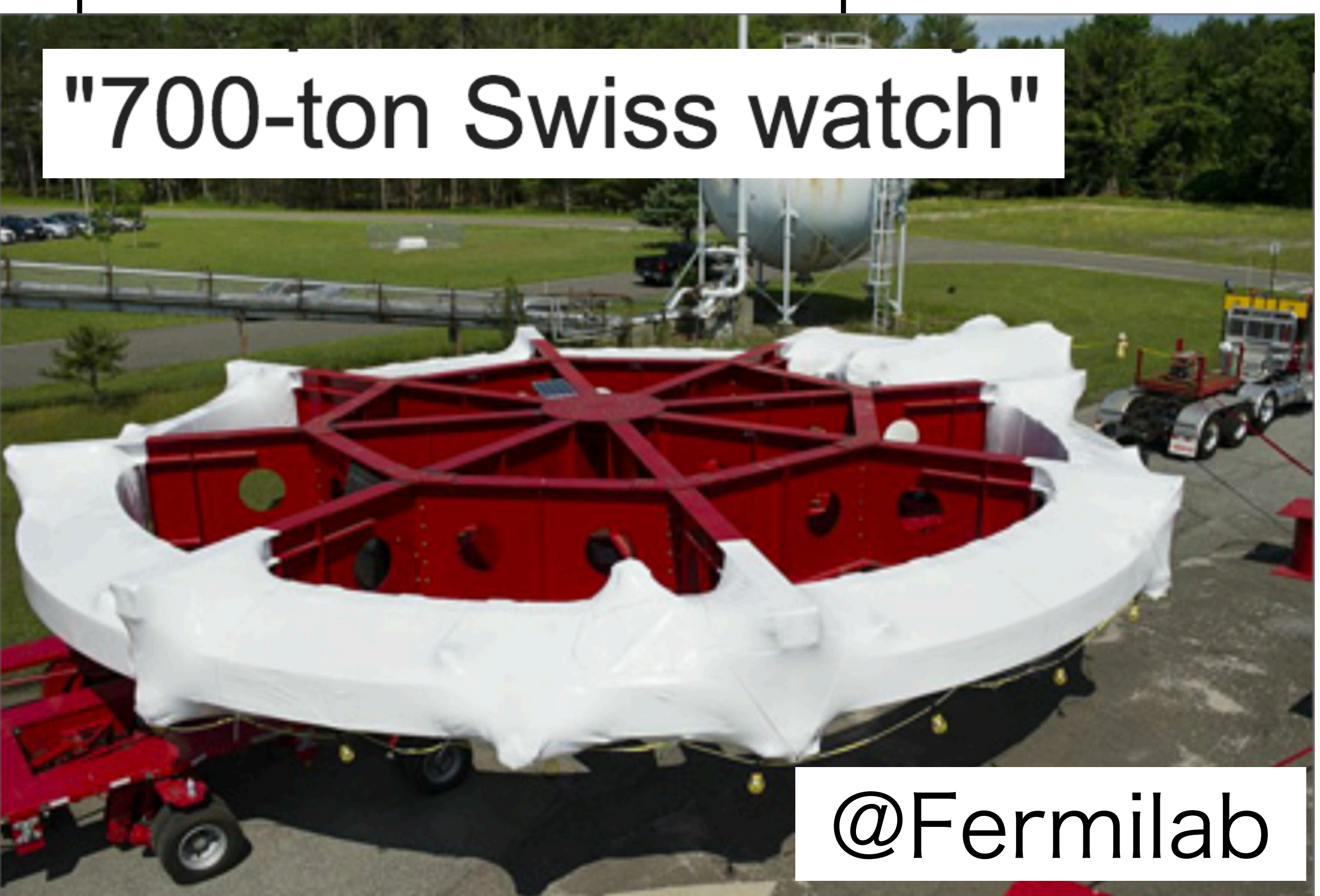


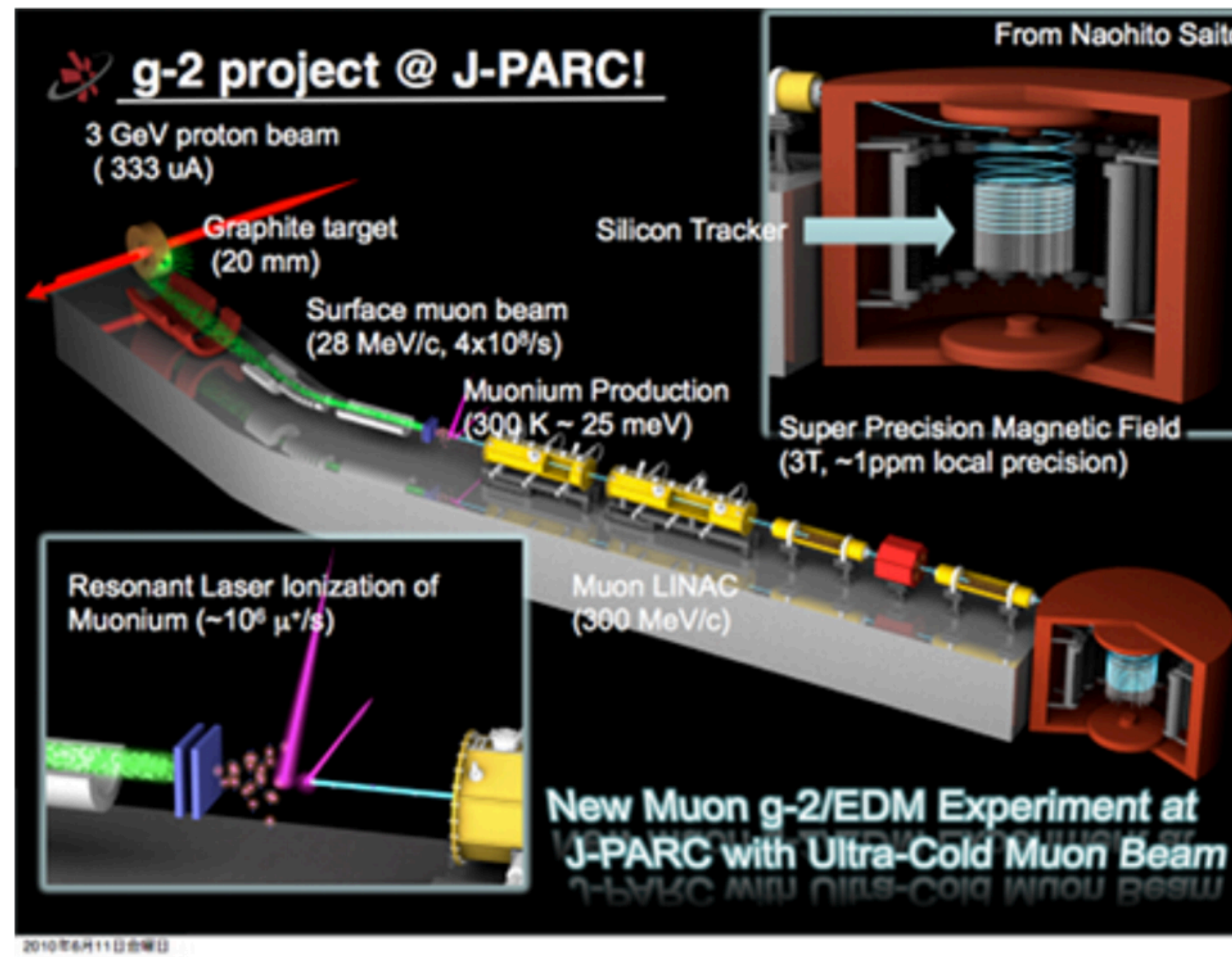
HVP



[10^{10}]

Experiment	11659208.9±1.6?





J-PARC g-2計画概略

$$a_\mu^{\mathrm{EXP}} - a_\mu^{\mathrm{SM}} = \begin{array}{ll} (26.1 \pm 5.2) \cdot 10^{-10} & \text{[HLMT]} \\ (28.7 \pm \quad\;) \cdot 10^{-10} & \text{[DHMZ]} \end{array}$$

~5σ

What is an expected NP mass scale to explain the muon g-2 ?

$$\Delta(a_\mu)_{\rm NP} \sim \frac{g^2}{16\pi^2}\frac{m_\mu^2}{m_{\rm NP}^2}$$
$$= 20.7\times 10^{-10}\left(\frac{g}{0.65}\right)^2\left(\frac{120{\rm GeV}}{m_{\rm NP}}\right)^2$$

New coupling

Mass scale of new physics

We need ~100GeV new particles.

In SUSY, $\tan\beta$ enhancement can help to explain this deviation

What is an expected NP mass scale to explain the muon g-2 ?

$$\Delta(a_\mu)_{\rm NP} \sim \frac{g^2}{16\pi^2}\frac{m_\mu^2}{m_{\rm NP}^2} \textbf{ x } \tan\beta$$

$$= 20.7\times 10^{-10}\left(\frac{g}{0.65}\right)^2\left(\frac{120{\rm GeV}}{m_{\rm NP}}\right)^2 \textbf{ x } \tan\beta$$

New coupling

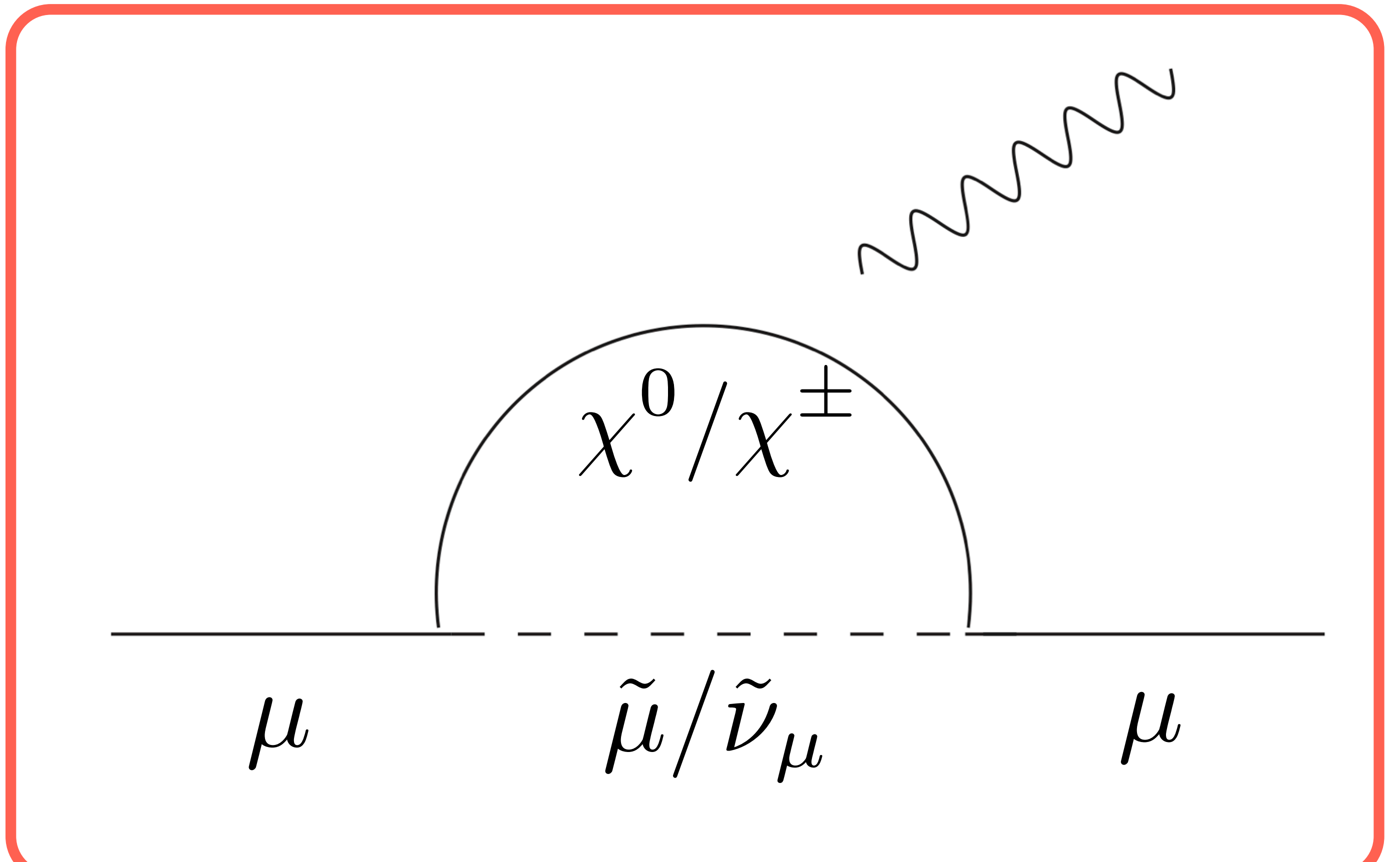
Mass scale of new physics

We need ~100GeV new particles.

In SUSY, $\tan\beta$ enhancement can help to explain this deviation

SUSY contributions to muon g-2

light smuons and neutralino/chargino
can explain this deviation

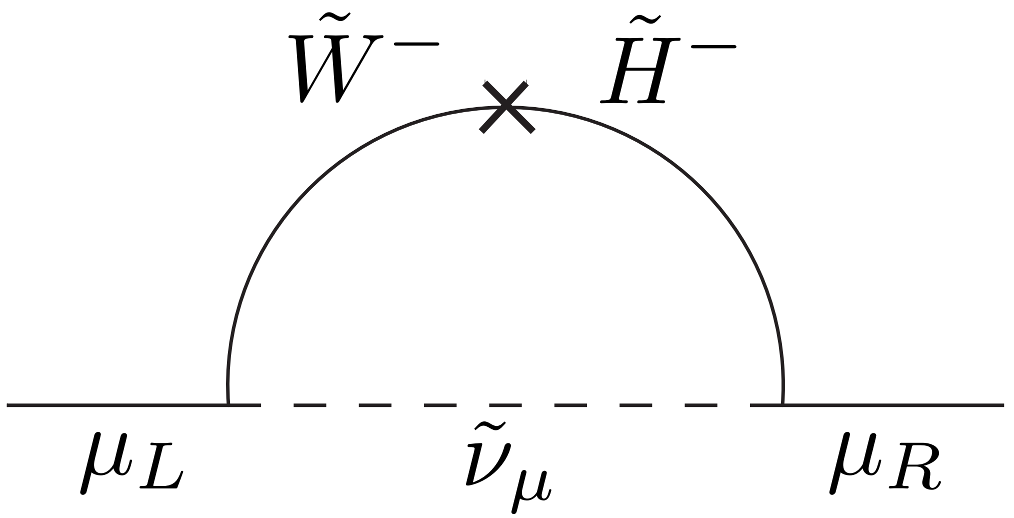


[J.L. Lopez, D.V. Nanopoulos, X. Wang '94; U. Chattopadhyay, P. Nath '95; T.Moroi '95]

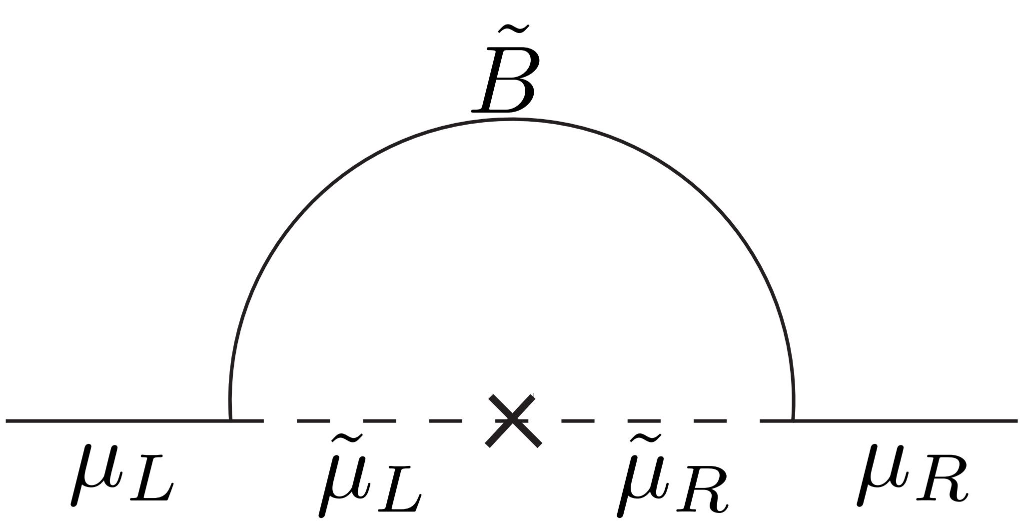
SUSY contributions to muon g-2

Two large SUSY contributions

Wino-Higgsino-sneutrino
(suppressed for large μ)



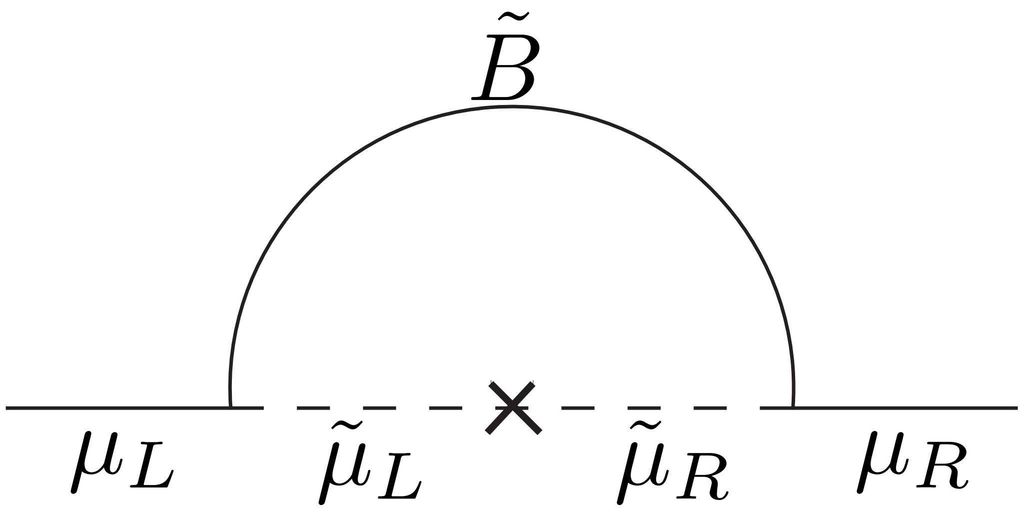
Bino-(L,R)smuon
(proportional to ~$\mu \tan\beta$)



SUSY contributions to muon g-2

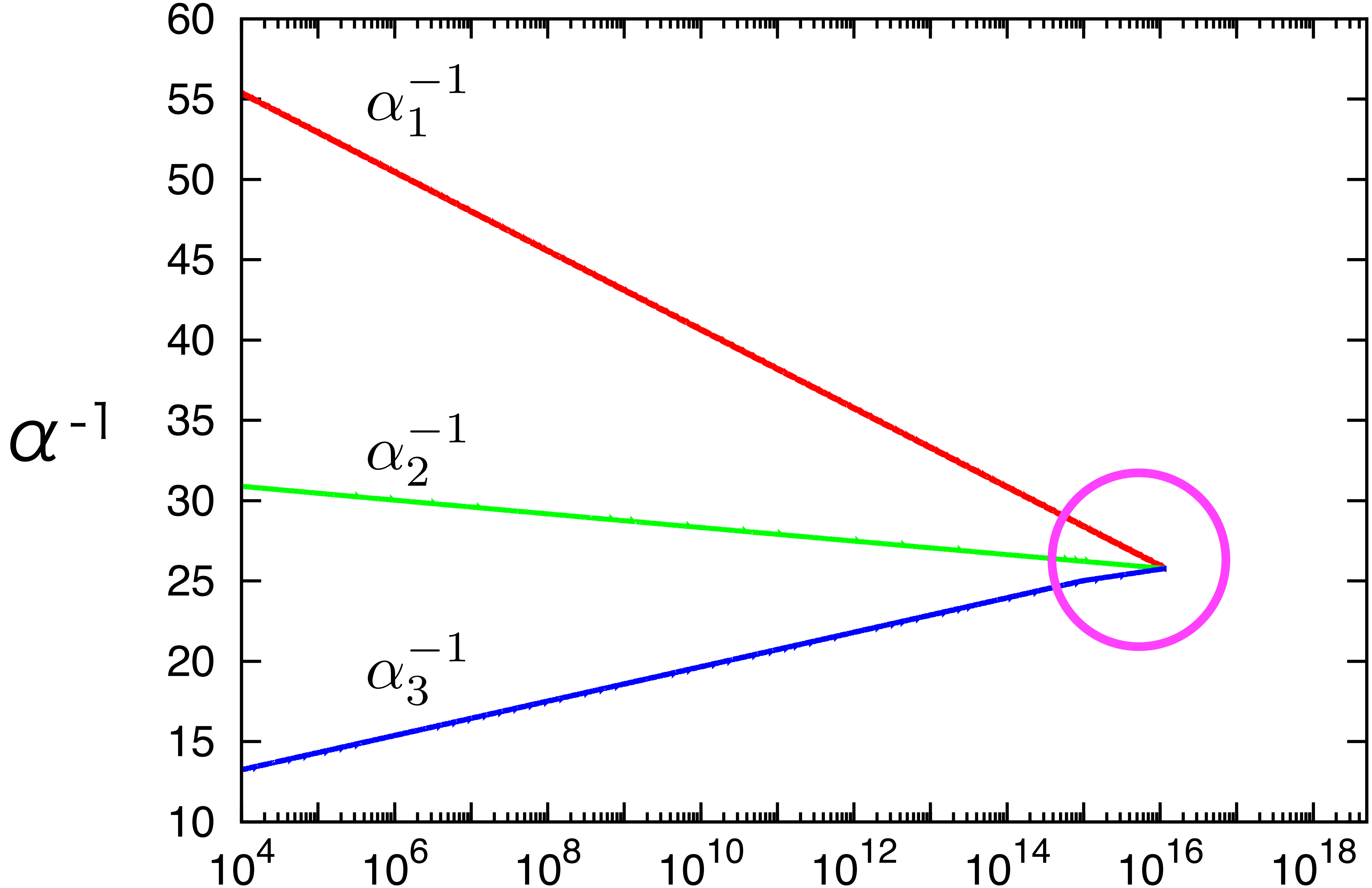
Bino contribution is important for mstop~μ~a few TeV.
Light Bino/smuons are required to explain the muon g-2

Bino-(L,R)smuon
(proportional to ~$\mu \tan\beta$)



A possible explanation exists within minimal SU(5)

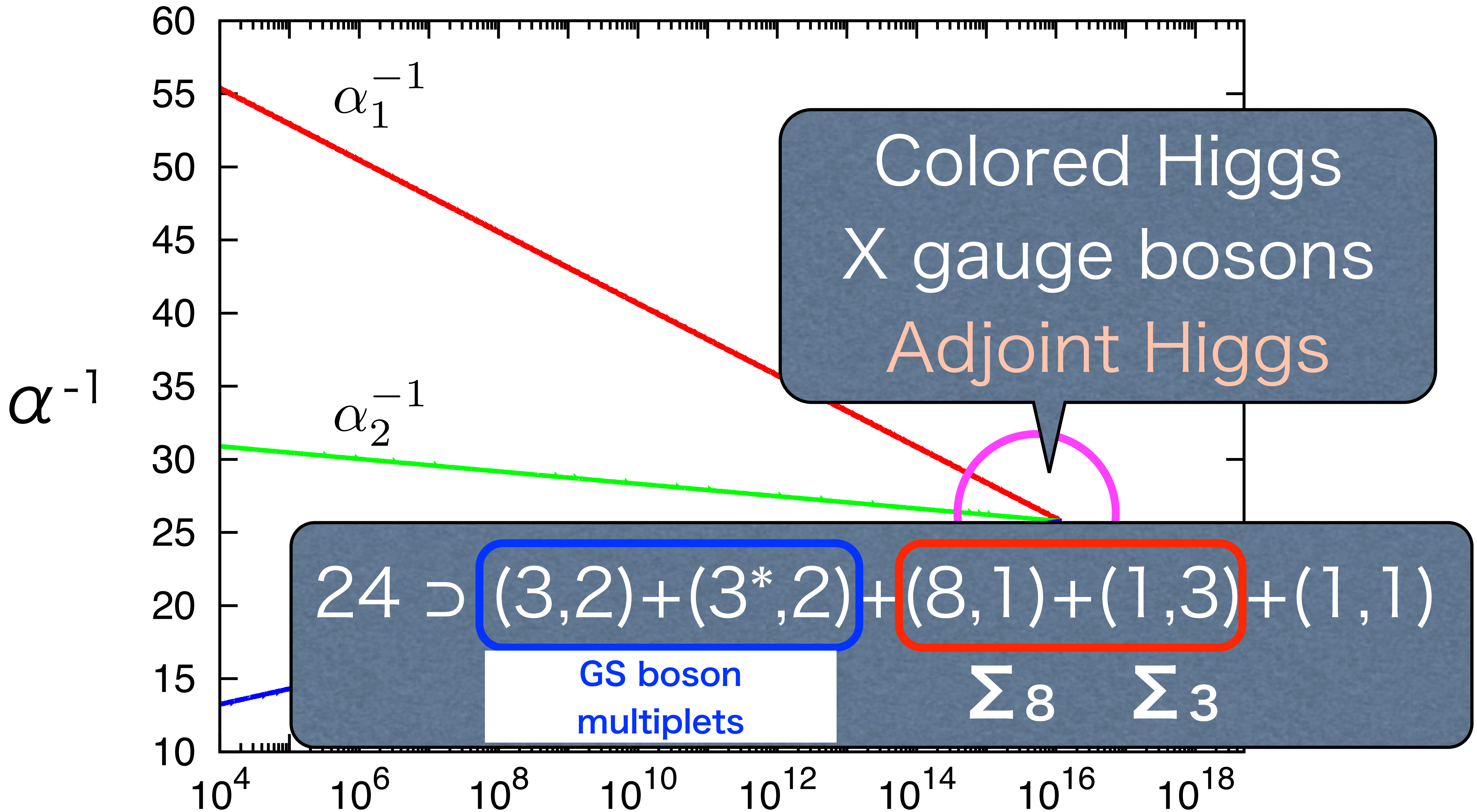
Gauge coupling unification in minimal SU(5)



Colored Higgs multiplets@10^{15}GeV

Proton decays quickly (┬_┬)

Gauge coupling unification in minimal SU(5)



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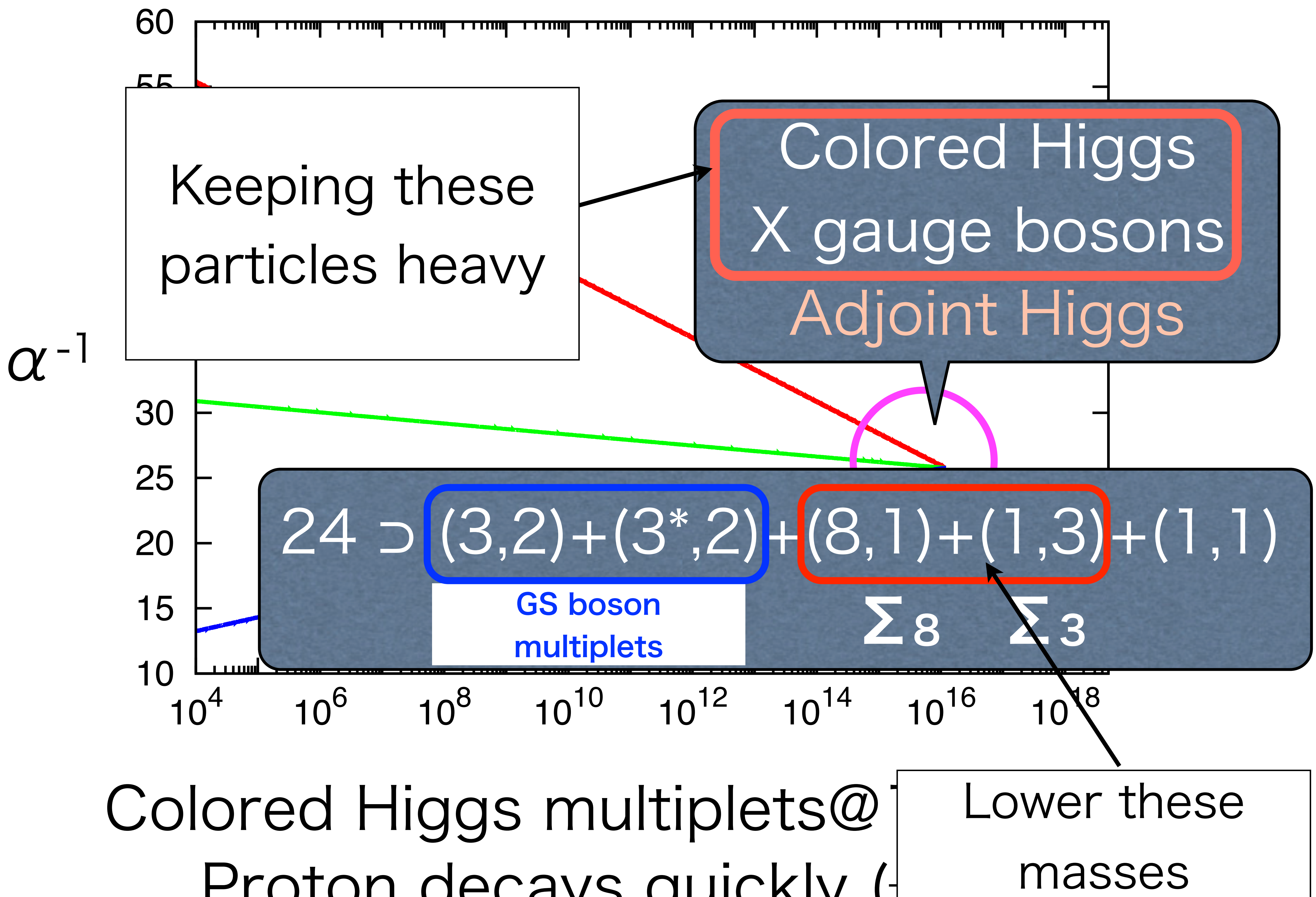
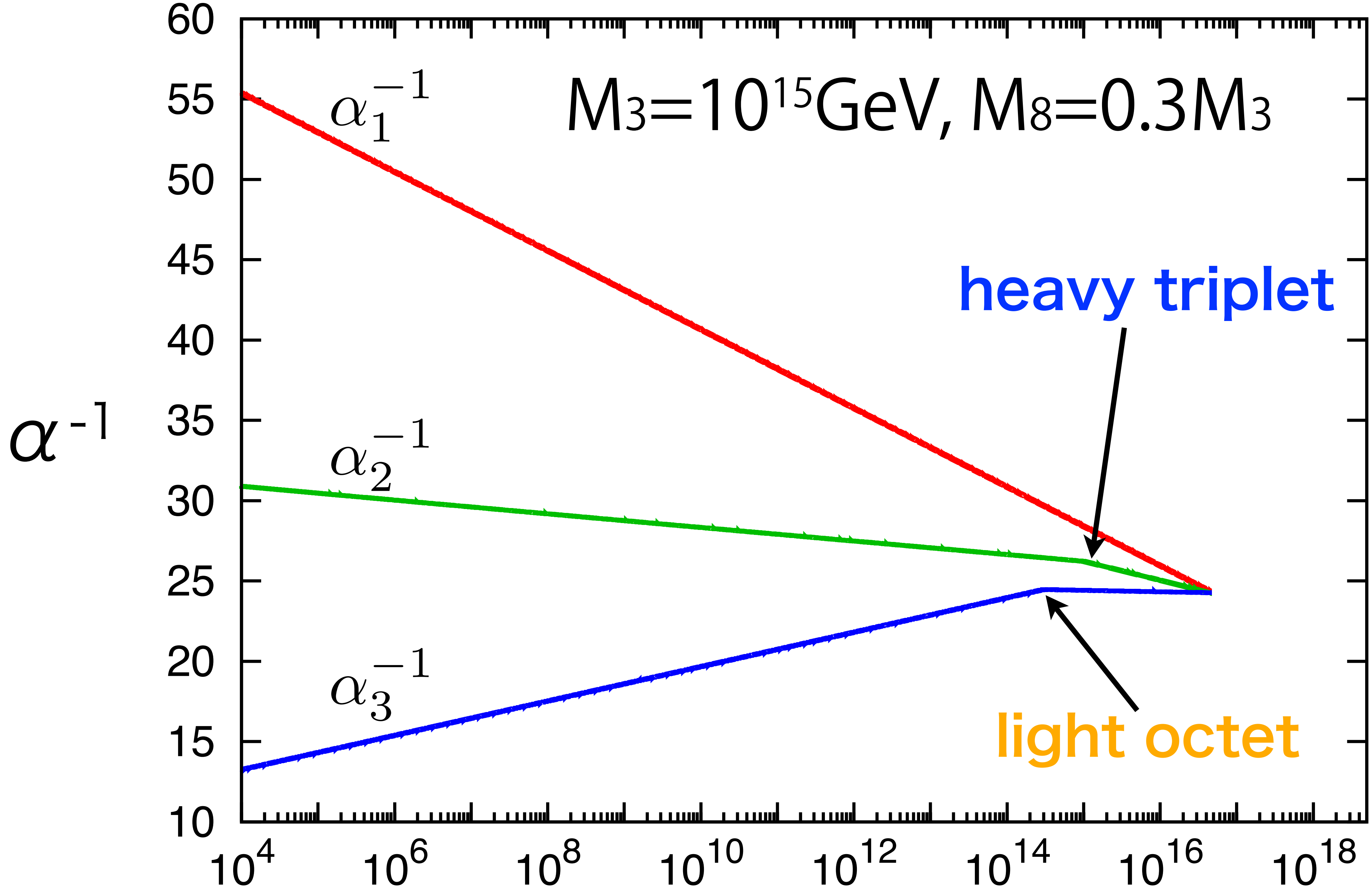


Colored Higgs multiplets@

Proton decays quickly (

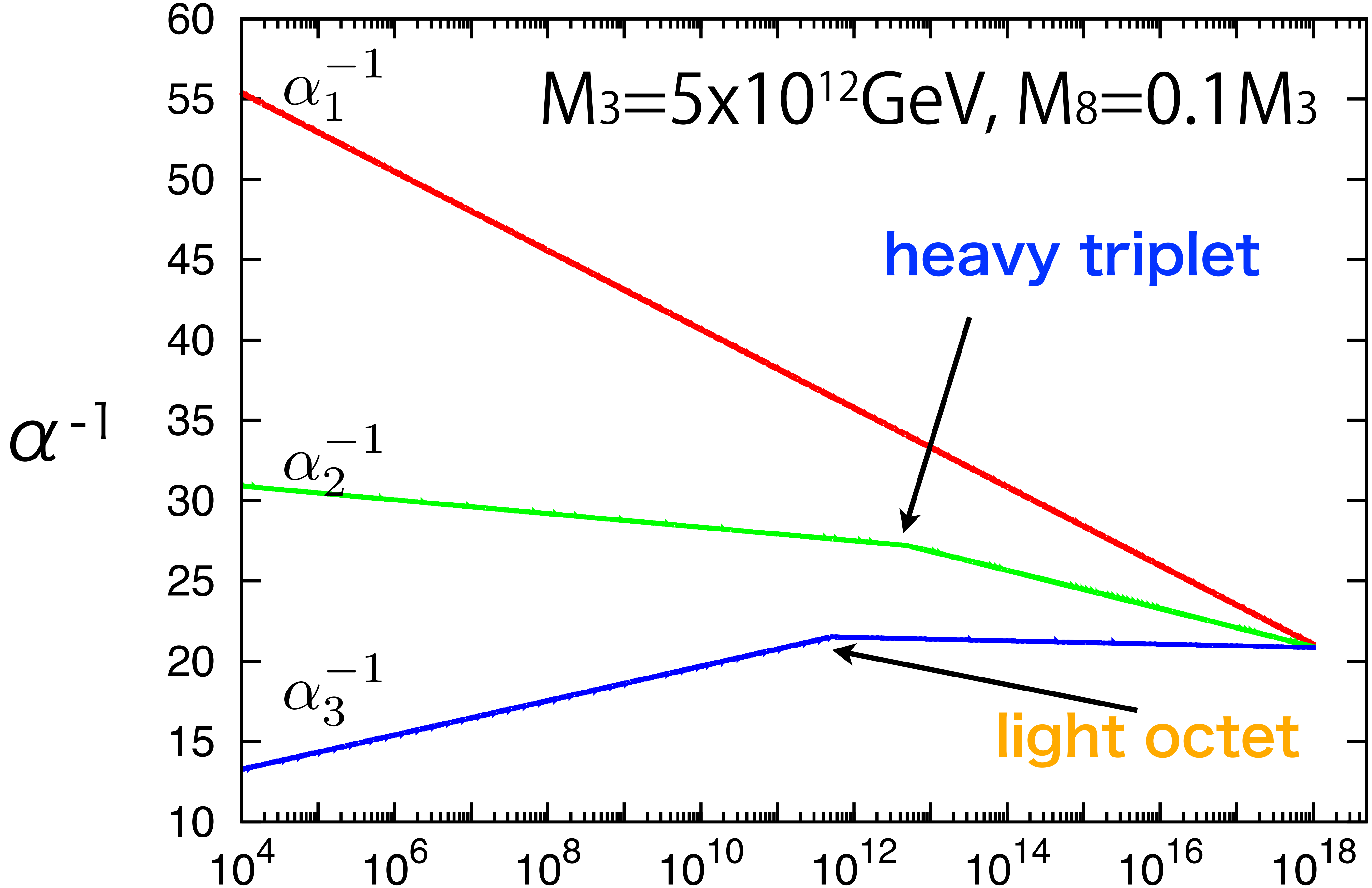
Gauge coupling unification in minimal SU(5)



Colored Higgs and gauge bosons are heavy

(*^_^*)

Gauge coupling unification in minimal SU(5)



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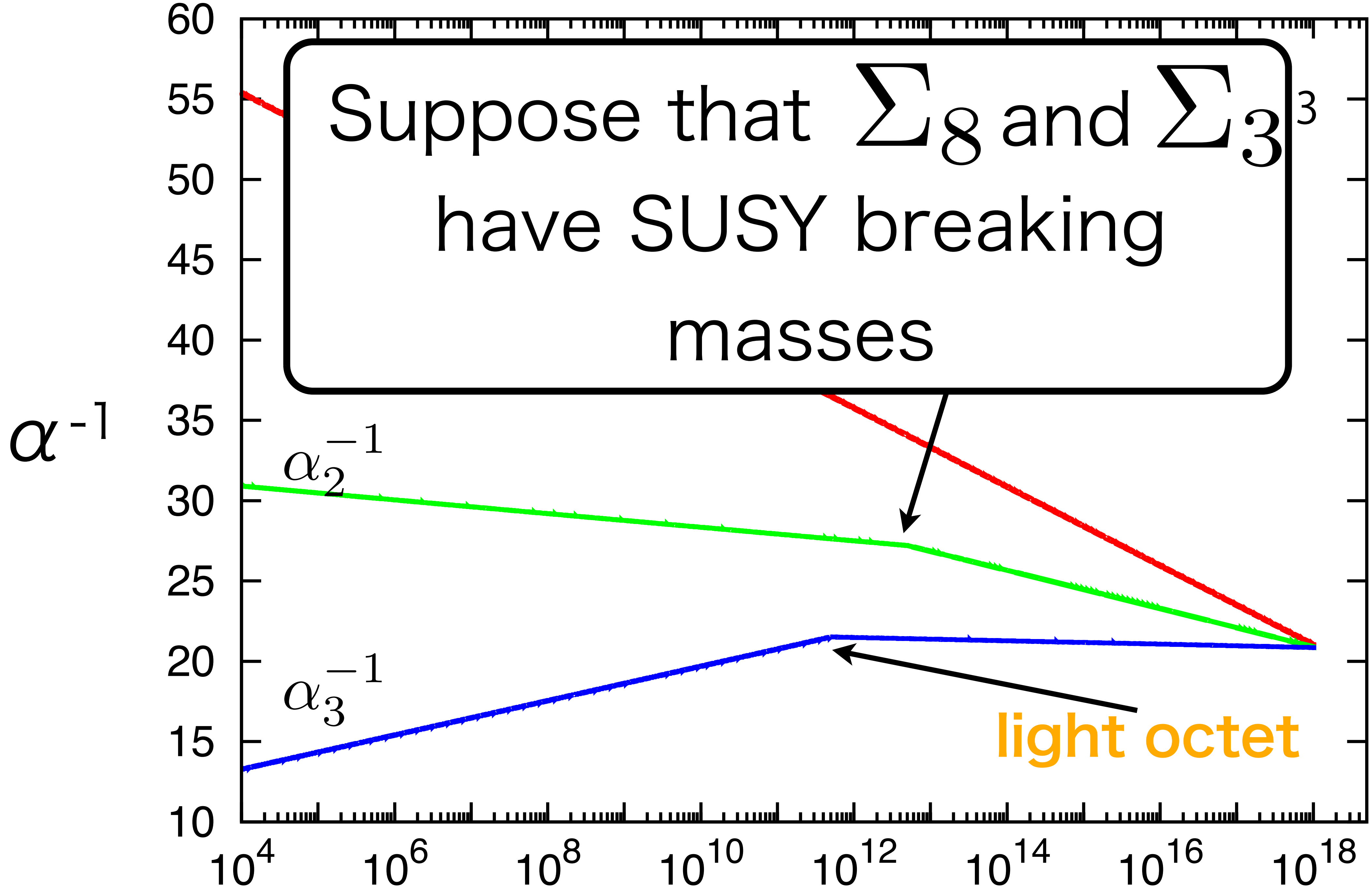

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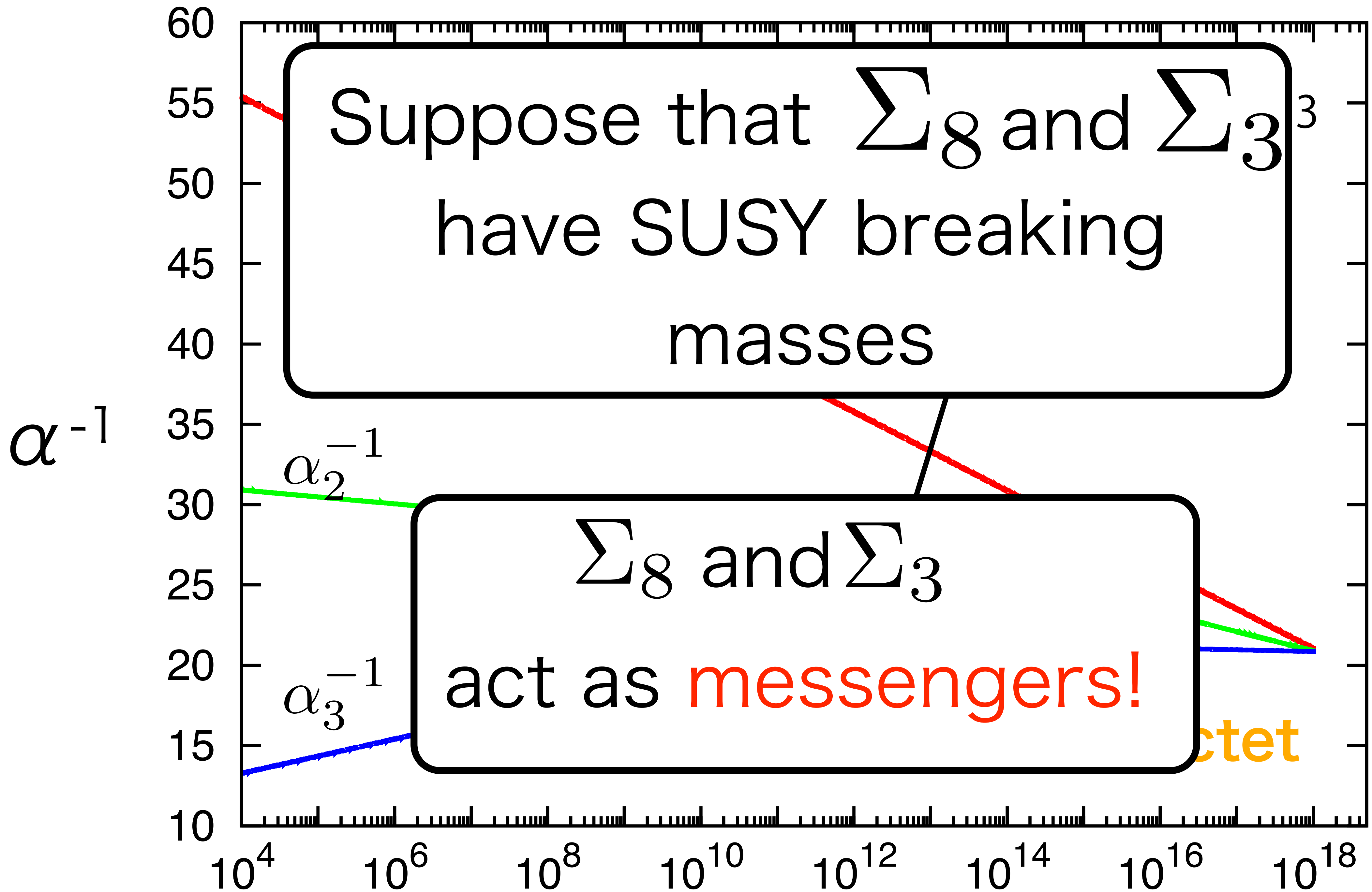


Colored Higgs and gauge bosons are heavy

(*^_^*)

Adjoint Messenger Model

$$W = (M_8 + \lambda F\theta^2)\mathrm{Tr}\Sigma_8^2$$
$$+(M_3 + \lambda F\theta^2)\mathrm{Tr}\Sigma_3^2$$

No hyper charge

Adjoint Messenger Model

$$W = (M_8 + \lambda F\theta^2)\mathrm{Tr}\Sigma_8^2$$
$$+(M_3 + \lambda F\theta^2)\mathrm{Tr}\Sigma_3^2$$

No hyper charge

heavy

$$M_3 \simeq \frac{\alpha_3}{4\pi}\frac{3\tilde{F}}{M_8} \quad m_{\tilde{Q}}^2 \sim m_{\tilde{U}}^2 = m_{\tilde{D}}^2 \simeq \frac{\alpha_3^2}{8\pi^2}4\frac{\tilde{F}^2}{M_8^2}$$

$$M_1 \simeq 0,\ M_2 \simeq \frac{\alpha_2}{4\pi}\frac{2\tilde{F}}{M_3} \quad m_{\tilde{E}}^2 \simeq 0 \quad m_{\tilde{L}}^2 \simeq \frac{1}{8\pi^2}\frac{3}{2}\alpha_2^2\frac{\tilde{F}^2}{M_3^2}$$

light

Massless Bino and right-handed sleptons are predicted!

Heavy triplet → light non-colored SUSY particles

Light octet → heavy colored SUSY particles

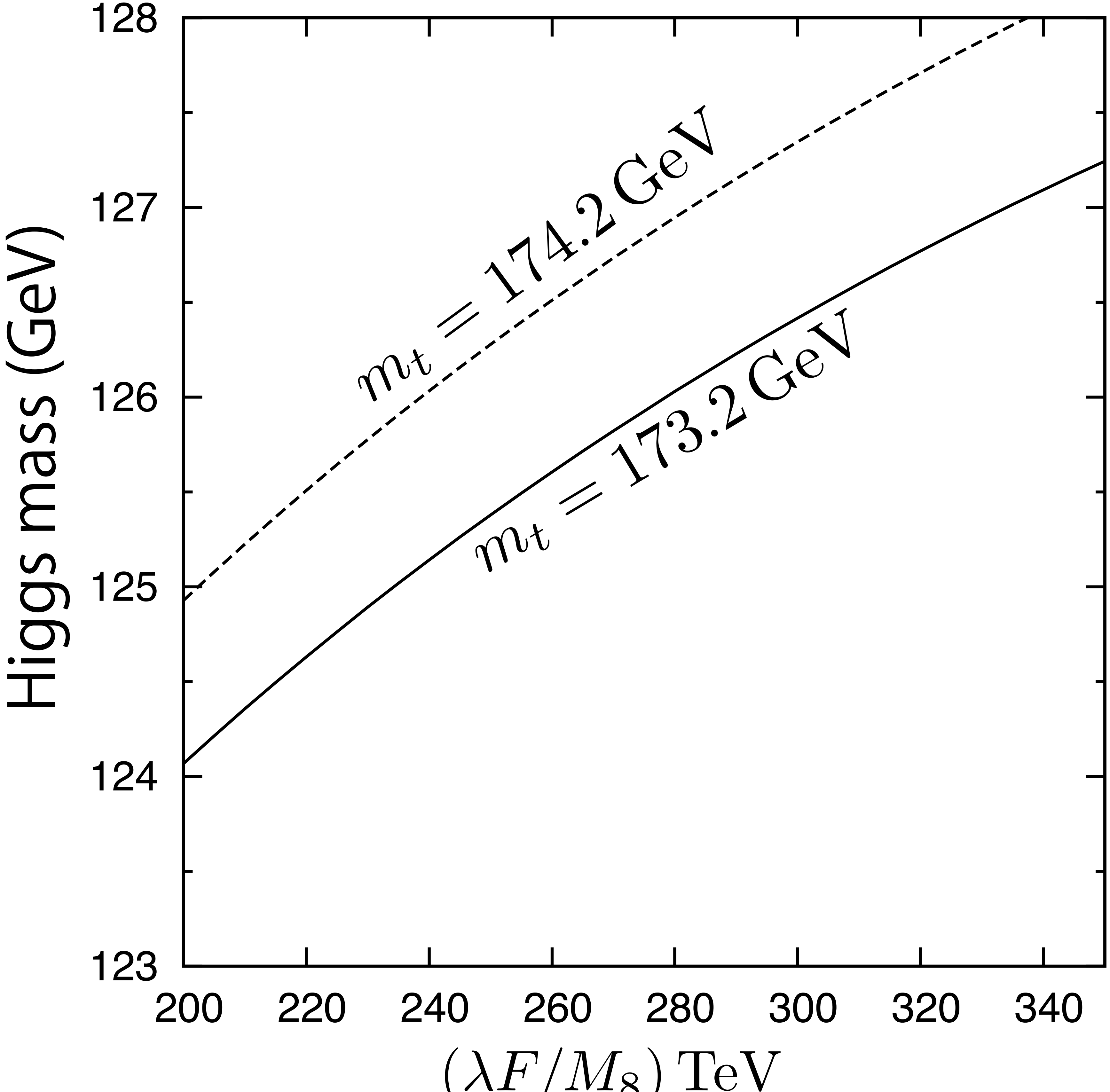
$$M_3 \simeq \frac{\alpha_3}{4\pi}\frac{3\tilde{F}}{M_8} \quad m^2_{\tilde{Q}} \sim m^2_{\tilde{U}} = m^2_{\tilde{D}} \simeq \frac{\alpha_3^2}{8\pi^2} 4 \frac{\tilde{F}^2}{M_8^2}$$

$$M_1 \simeq 0, \; M_2 \simeq \frac{\alpha_2}{4\pi}\frac{2\tilde{F}}{M_3} \quad m^2_{\tilde{E}} \simeq 0 \quad m^2_{\tilde{L}} \simeq \frac{1}{8\pi^2}\frac{3}{2}\alpha_2^2 \frac{\tilde{F}^2}{M_3^2}$$

light

Results

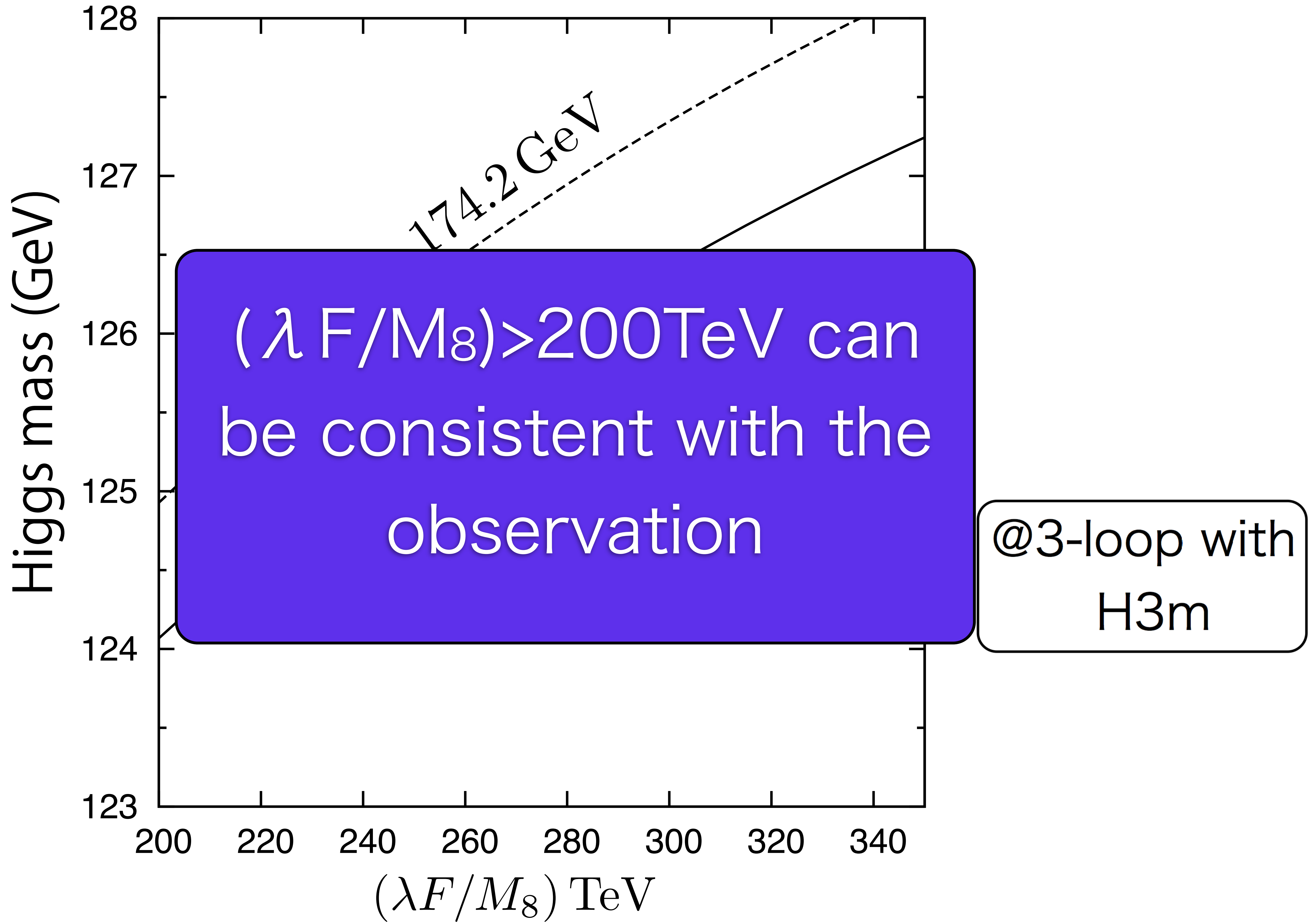
$M_{\rm mess} = 10^{11}\,{\rm GeV},\ \tan\beta = 10,\ m_0 = M_{1/2} = 300\,{\rm GeV}$



@3-loop with H3m

m$_{\rm stop}$~ $3.6 - 5.1$ TeV

$M_{\rm mess} = 10^{11}\,{\rm GeV},\ \tan\beta = 10,\ m_0 = M_{1/2} = 300\,{\rm GeV}$



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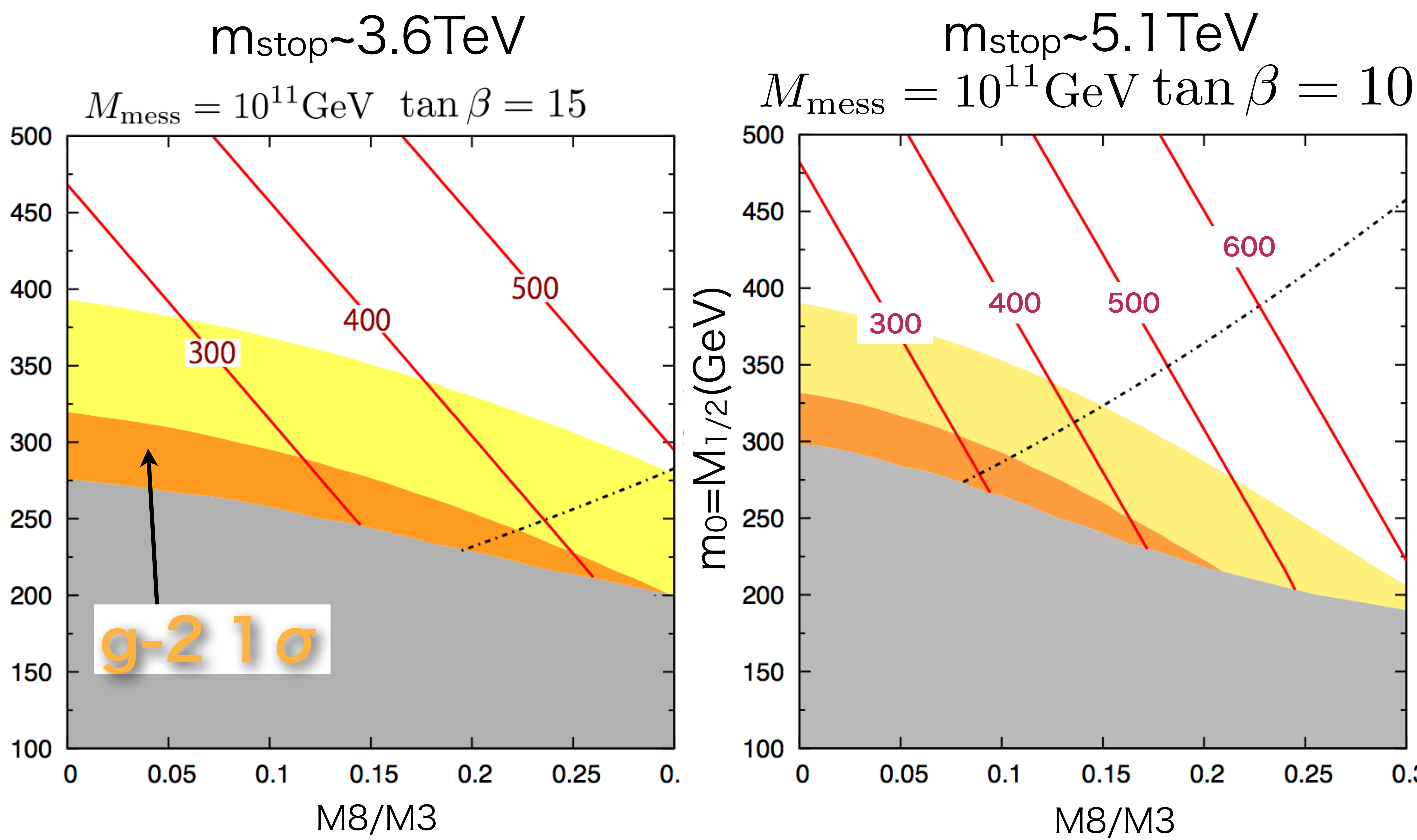
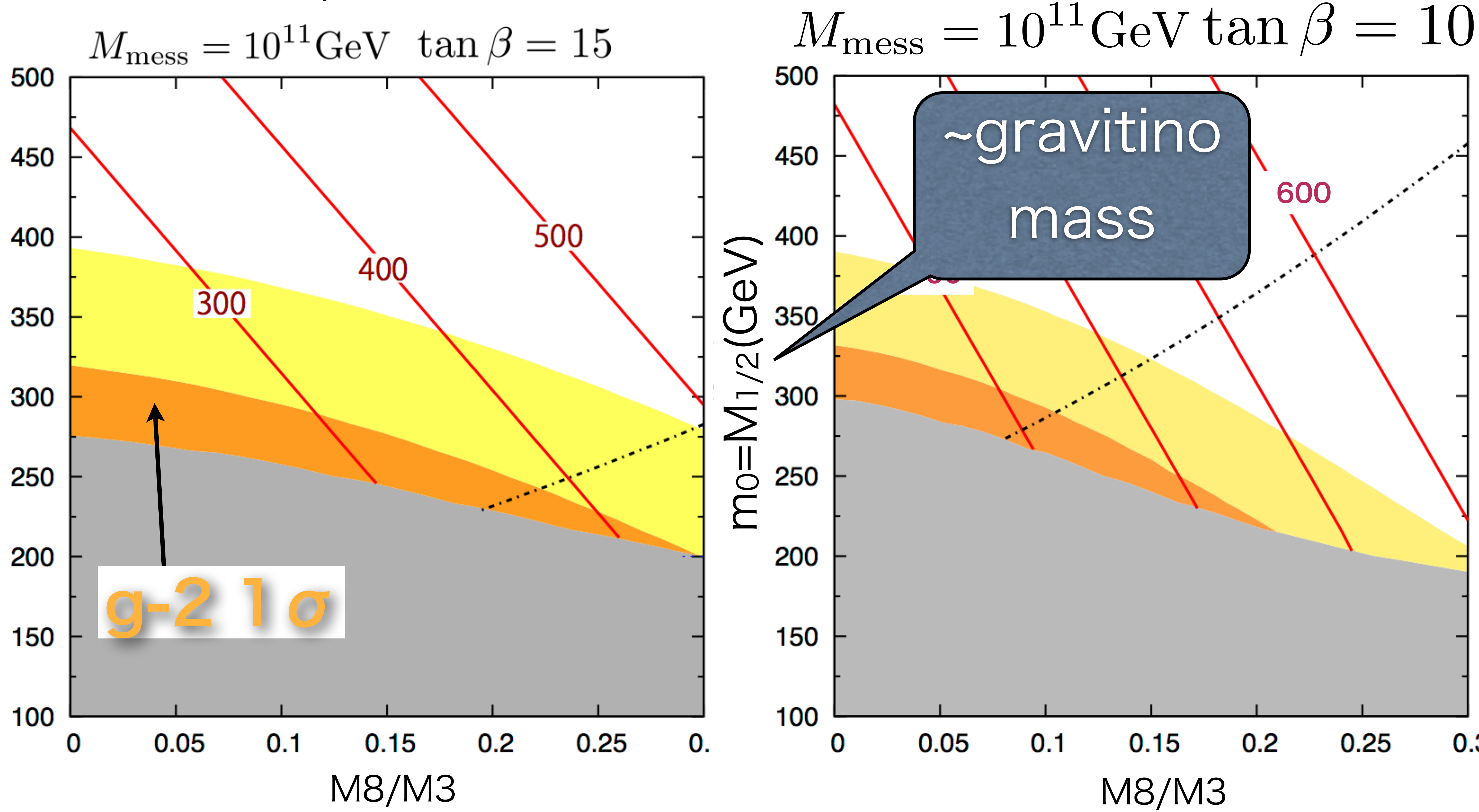


In whole region, neutralino is NLSP

m_{stop}~3.6TeV m_{stop}~5.1TeV



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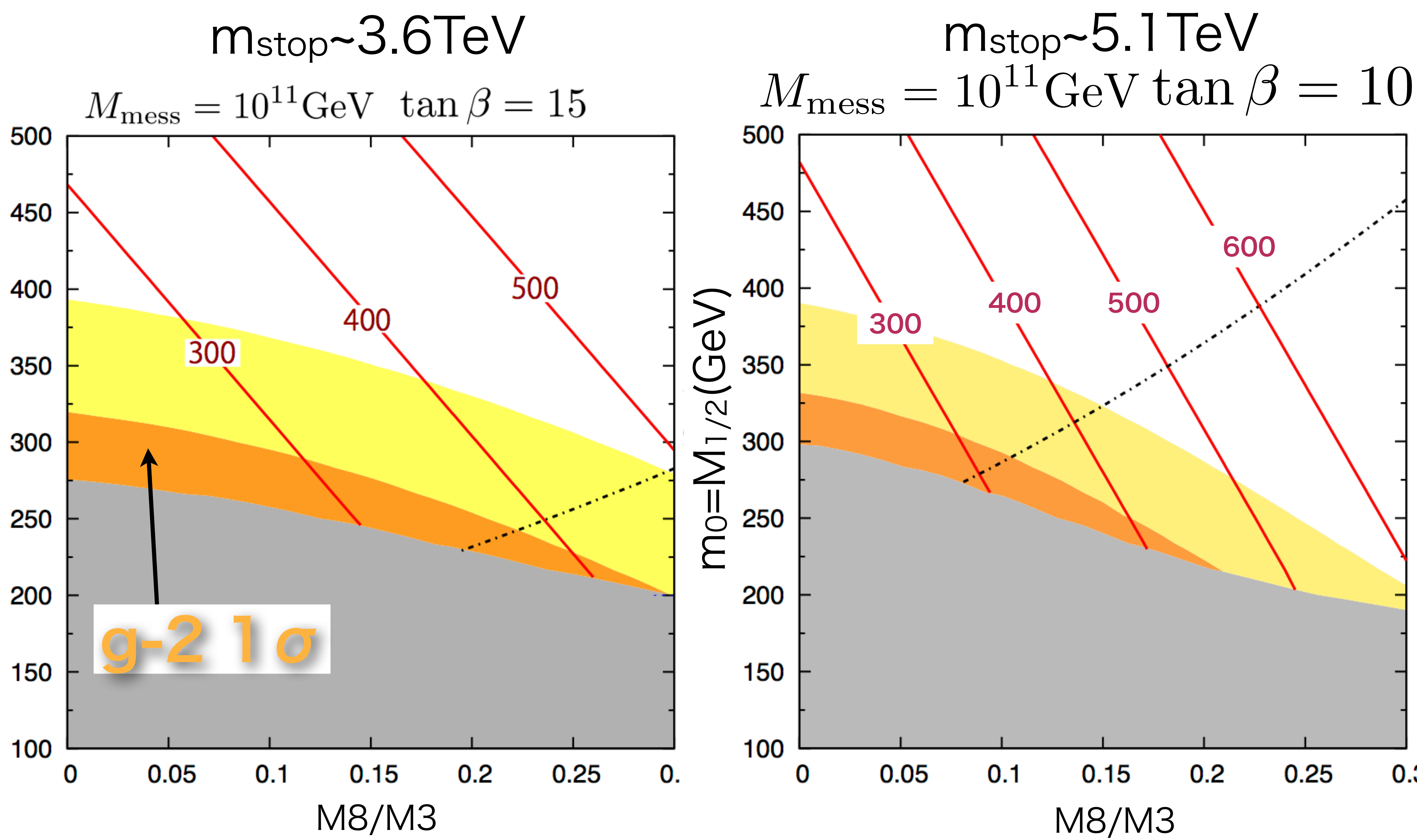

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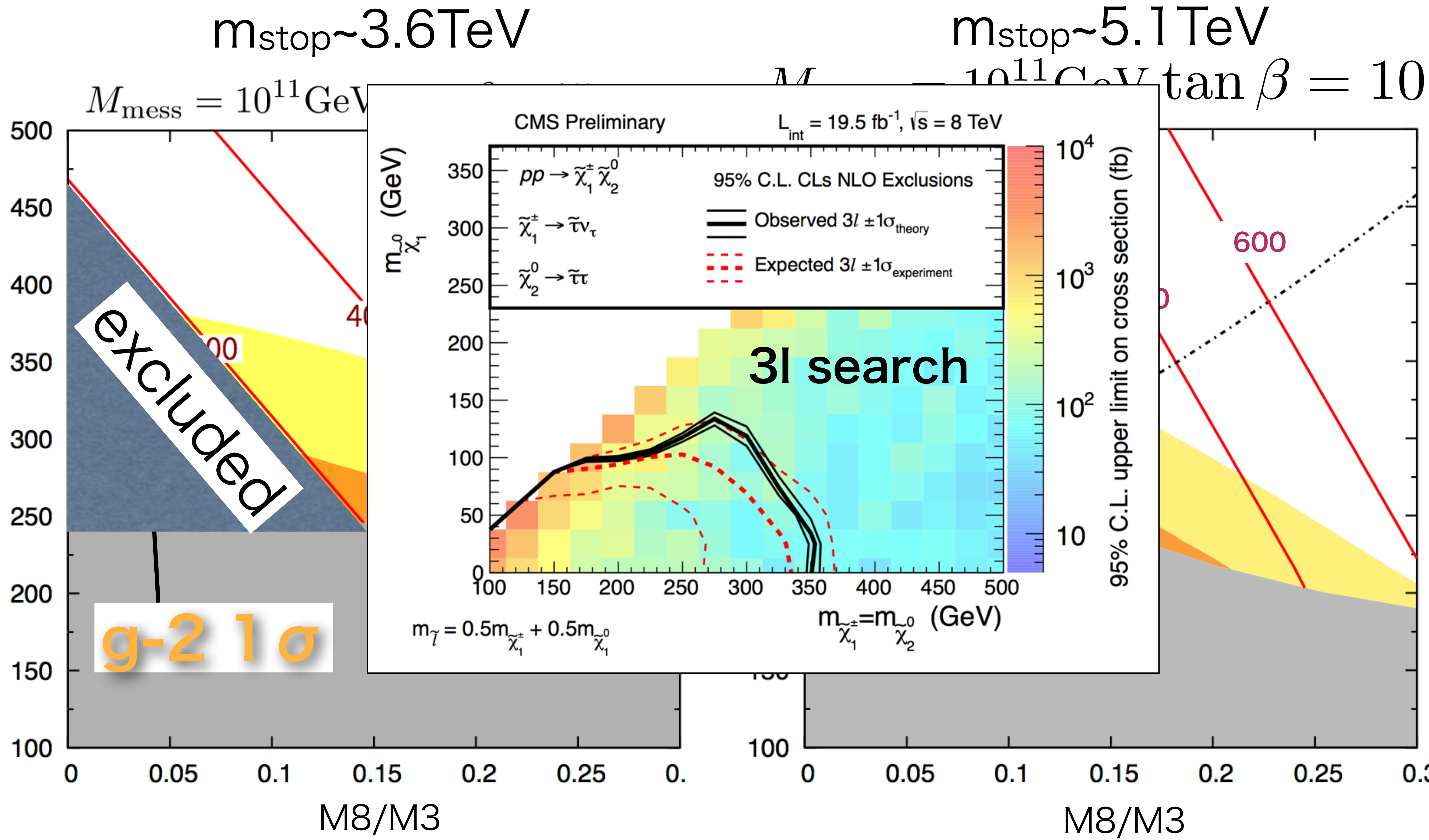

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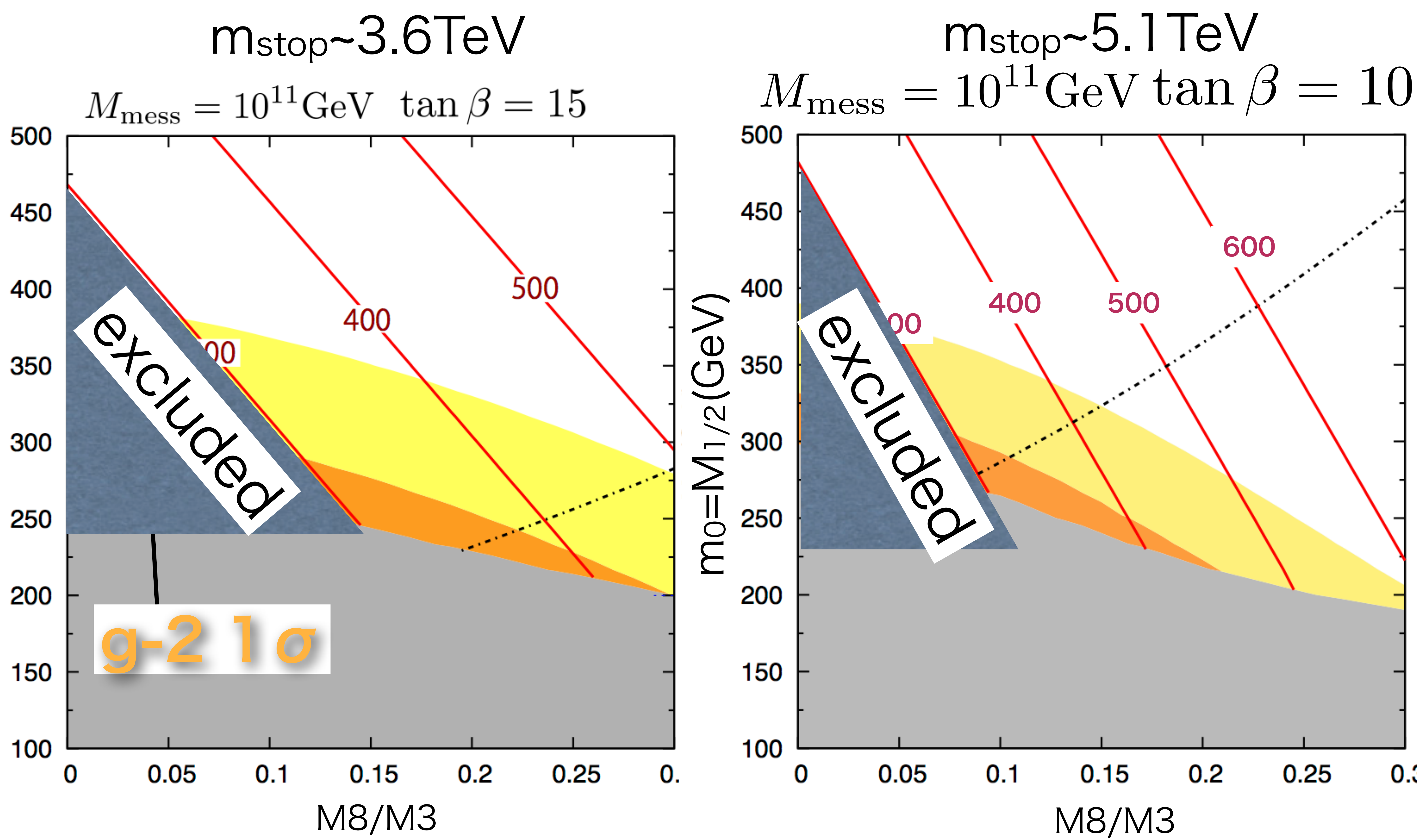

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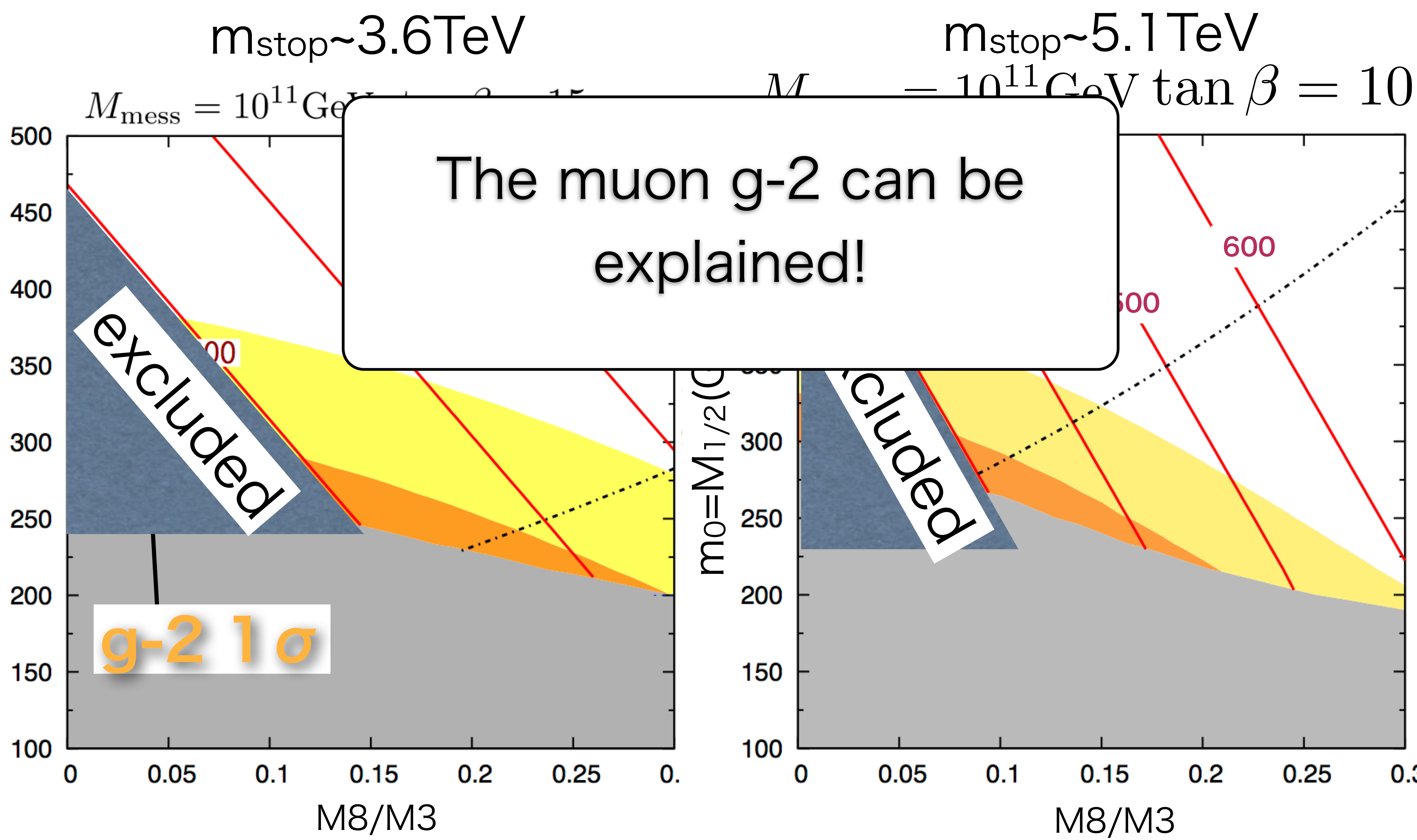

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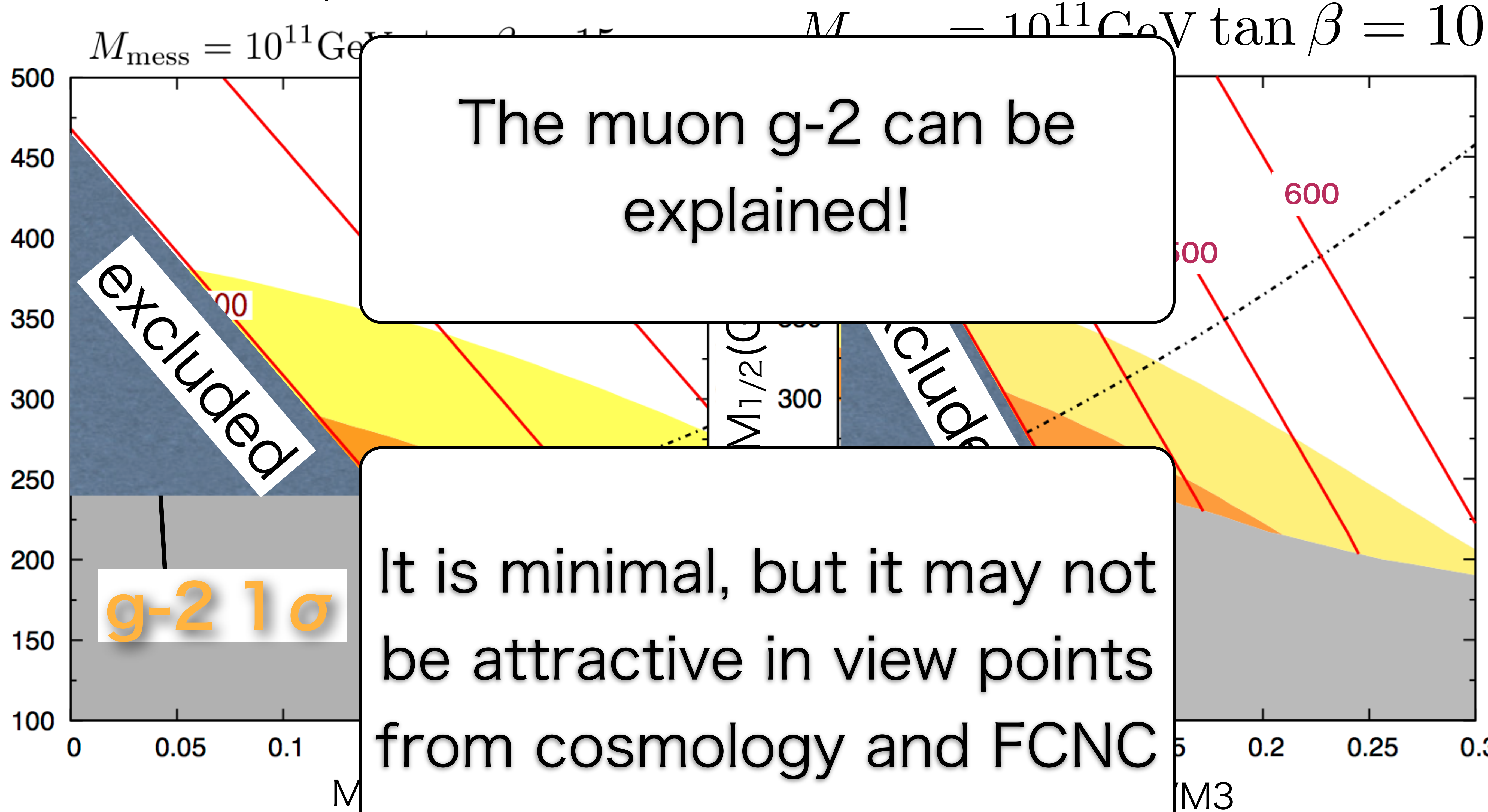
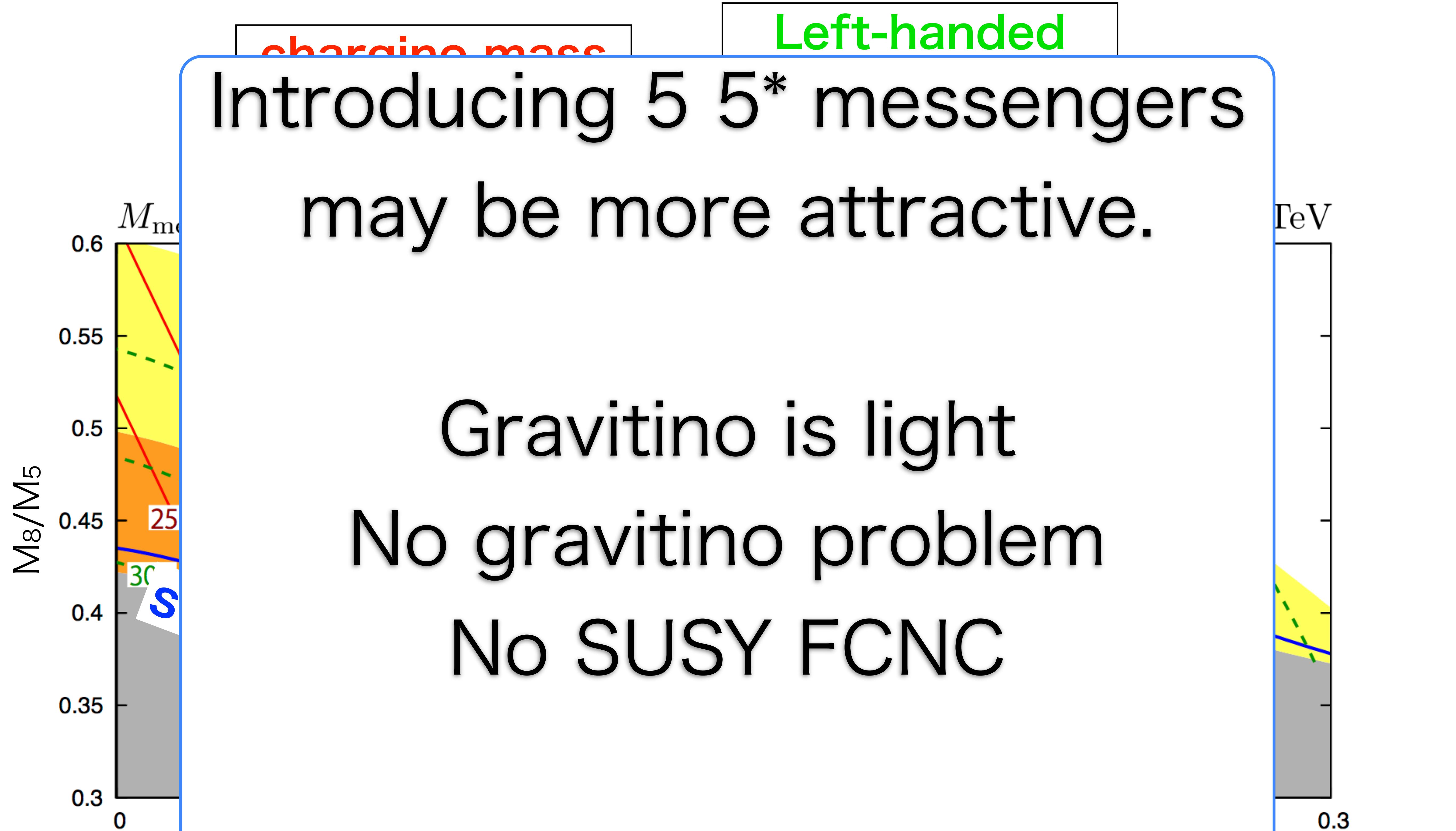


The muon g-2 can be explained!

It is minimal, but it may not be attractive in view points from cosmology and FCNC

In whole region, neutralino is NLSP



Introducing 5 5* messengers may be more attractive.

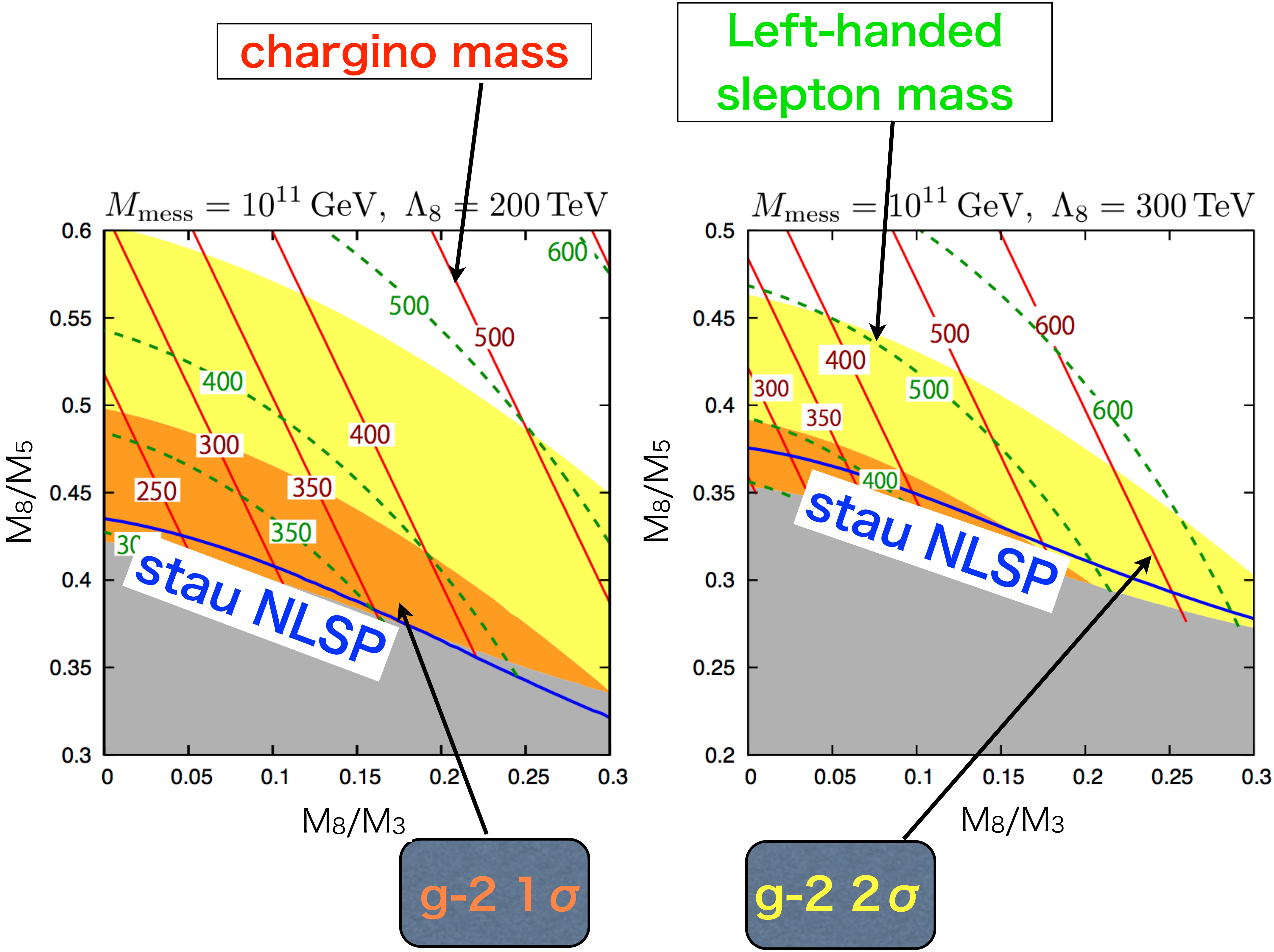
Gravitino is light

No gravitino problem

No SUSY FCNC

Note: 5 5* do not affect the gauge coupling unification

Stable stau is excluded for mstau < 340GeV



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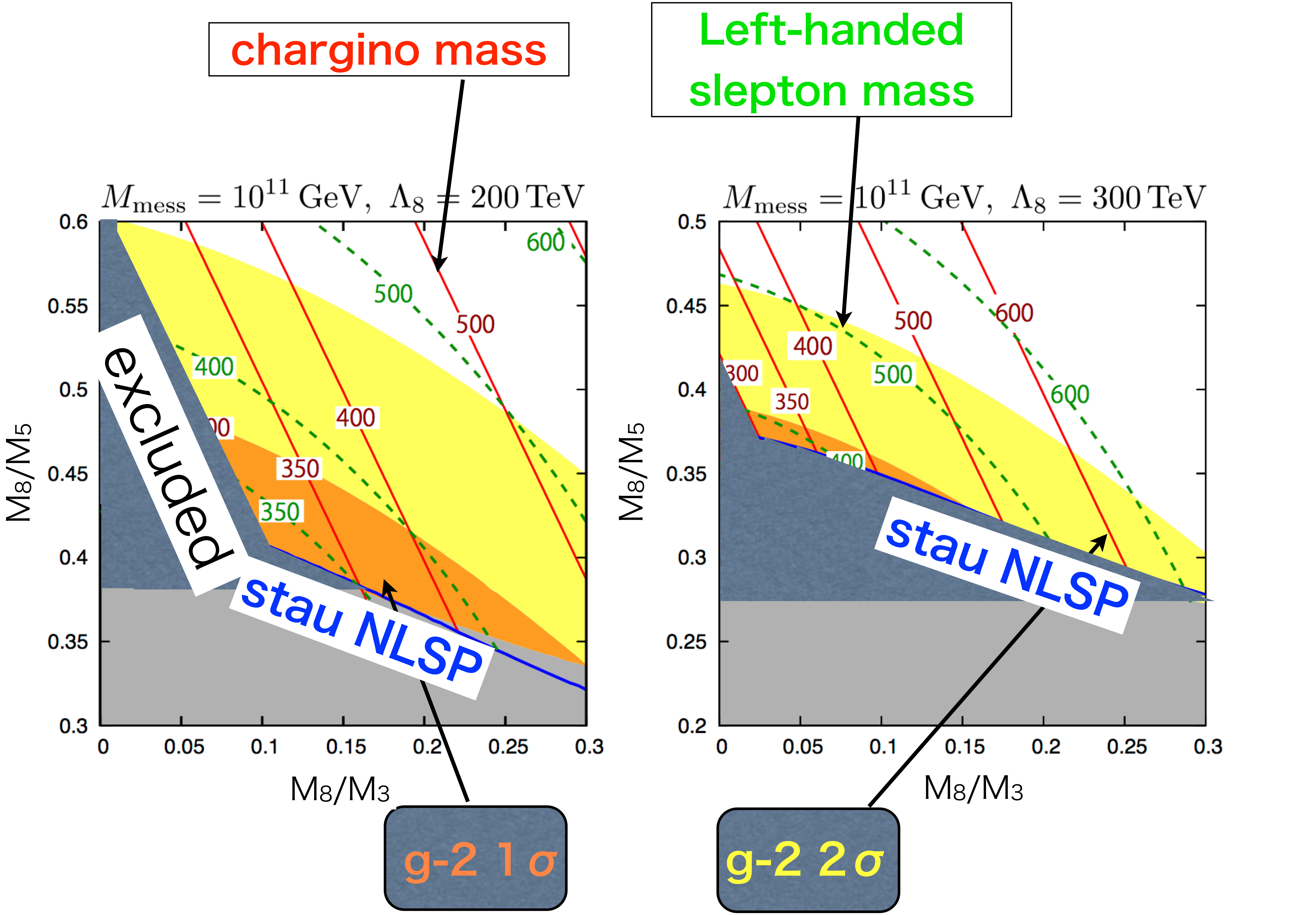
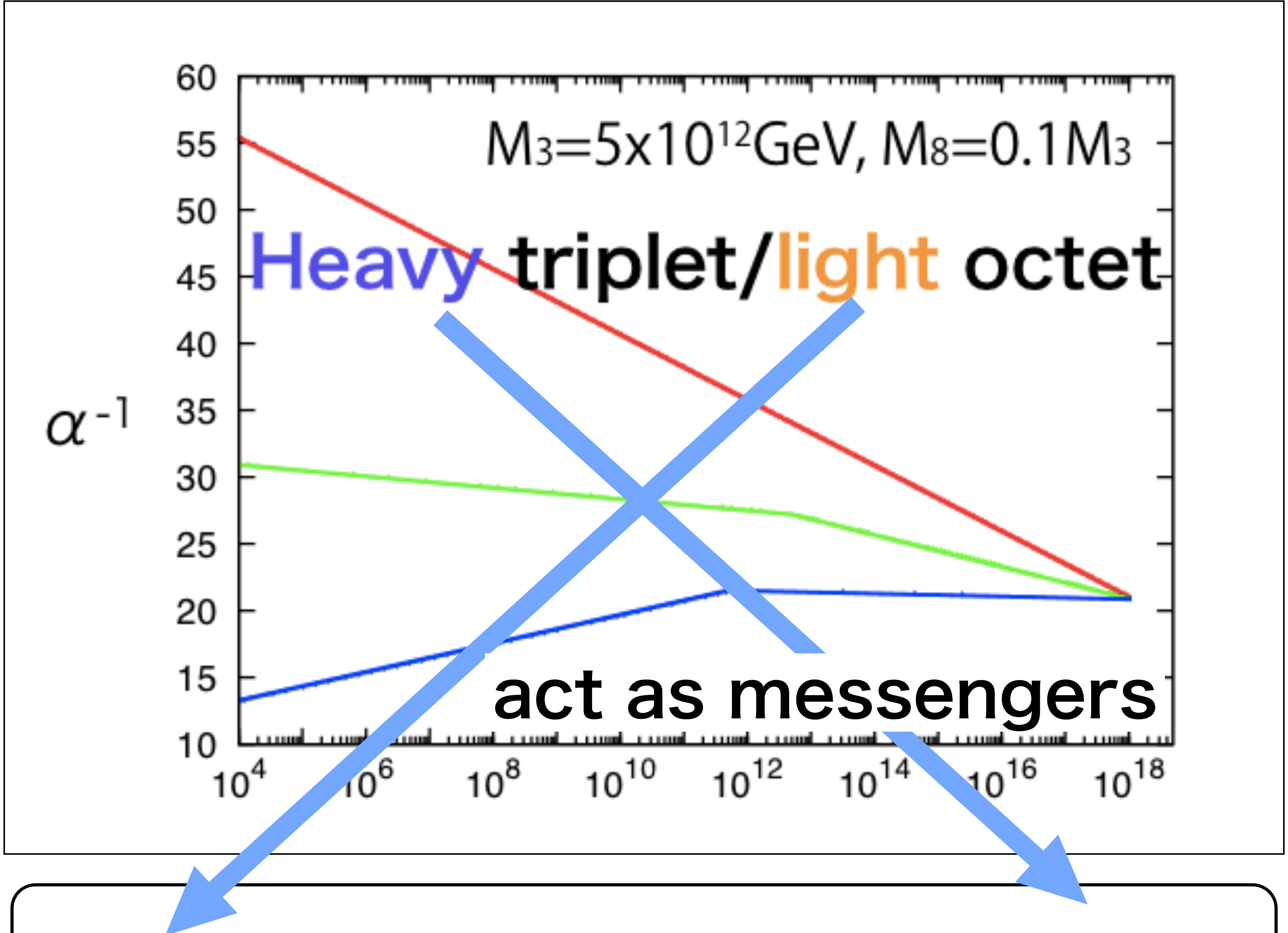


Stable stau is excluded for mstau < 340GeV

Mass spectrum

μ	2.4 TeV	μ	3.5 TeV
$m_{\rm stop}$	3.6 TeV	$m_{\rm stop}$	5.1 TeV
δa_μ	20.3×10^{-10}	δa_μ	18.6×10^{-10}
$m_{\rm gluino}$	4.4 TeV	$m_{\rm gluino}$	6.3 TeV
$m_{\rm squark}$	4.1 TeV	$m_{\rm squark}$	5.8 TeV
$m_{\tilde{e}_L}(m_{\tilde{\mu}_L})$	379 GeV	$m_{\tilde{e}_L}(m_{\tilde{\mu}_L})$	425 GeV
$m_{\tilde{e}_R}(m_{\tilde{\mu}_R})$	181 GeV	$m_{\tilde{e}_R}(m_{\tilde{\mu}_R})$	218 GeV
$m_{\tilde{\tau}_1}$	123 GeV	$m_{\tilde{\tau}_1}$	133 GeV
$m_{\chi_1^0}$	100 GeV	$m_{\chi_1^0}$	128 GeV
$m_{\chi_1^\pm}/m_{\chi_2^0}$	375 GeV	$m_{\chi_1^\pm}/m_{\chi_2^0}$	411 GeV

Table 1: Some reference mass spectra and $(\delta a_\mu)_{\rm SUSY}$.



Heavy colored particle and light non-colored particles are predicted

M_8/M_3	0.17	M_8/M_3	0.11
M_8/M_5	0.41	M_8/M_5	0.35
Λ_8	200 TeV	Λ_8	300 TeV
$M_{\rm mess}$	10^{11} GeV	$M_{\rm mess}$	10^{11} GeV
$\tan\beta$	10	$\tan\beta$	10
μ	2.4 TeV	μ	3.5 TeV
$m_{\rm stop}$	3.6 TeV	$m_{\rm stop}$	5.1 TeV
δa_μ	20.3×10^{-10}	δa_μ	18.6×10^{-10}
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Table 1: Some reference mass spectra and $(\delta a_\mu)_{\rm SUSY}$.

Summary

If the fine-tuning of the EWSB scale is important guiding principle, focus-point scenarios are attractive!

If the anomaly of the muon g-2 is true, GMSB models with SU(3) octet and SU(2) triplet messengers can solve this anomaly.

Summary

If the fin ale is
import cus-
poin e!

Prediction!

Light Higgsino

If the anomaly of the muon g-2 is true, GMSB models with SU(3) octet and SU(2) triplet messengers can solve this anomaly.

Summary

If the fin… …ale is
import… …cus-
poin… …e!

Prediction!
Light Higgsino

If the anomaly of the muon g-2 is
true, Gl… …ctet
and S… …an
solve this anomaly.

Prediction!
Light sleptons

Thank you very much!