2013/11/12@LCWS

A gauge mediation model for explaining the muon g-2 with gauge coupling unification

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in collaboration with

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Phys.Lett. B725 (2013) 339-343

arXiv:1311.1906

Introduction

2013 Physics Prize

Photo: G-M Greuel via Wikimedia Commons

Peter Higgs

Photo: Pnicolet via Wikimedia Commons

François Englert

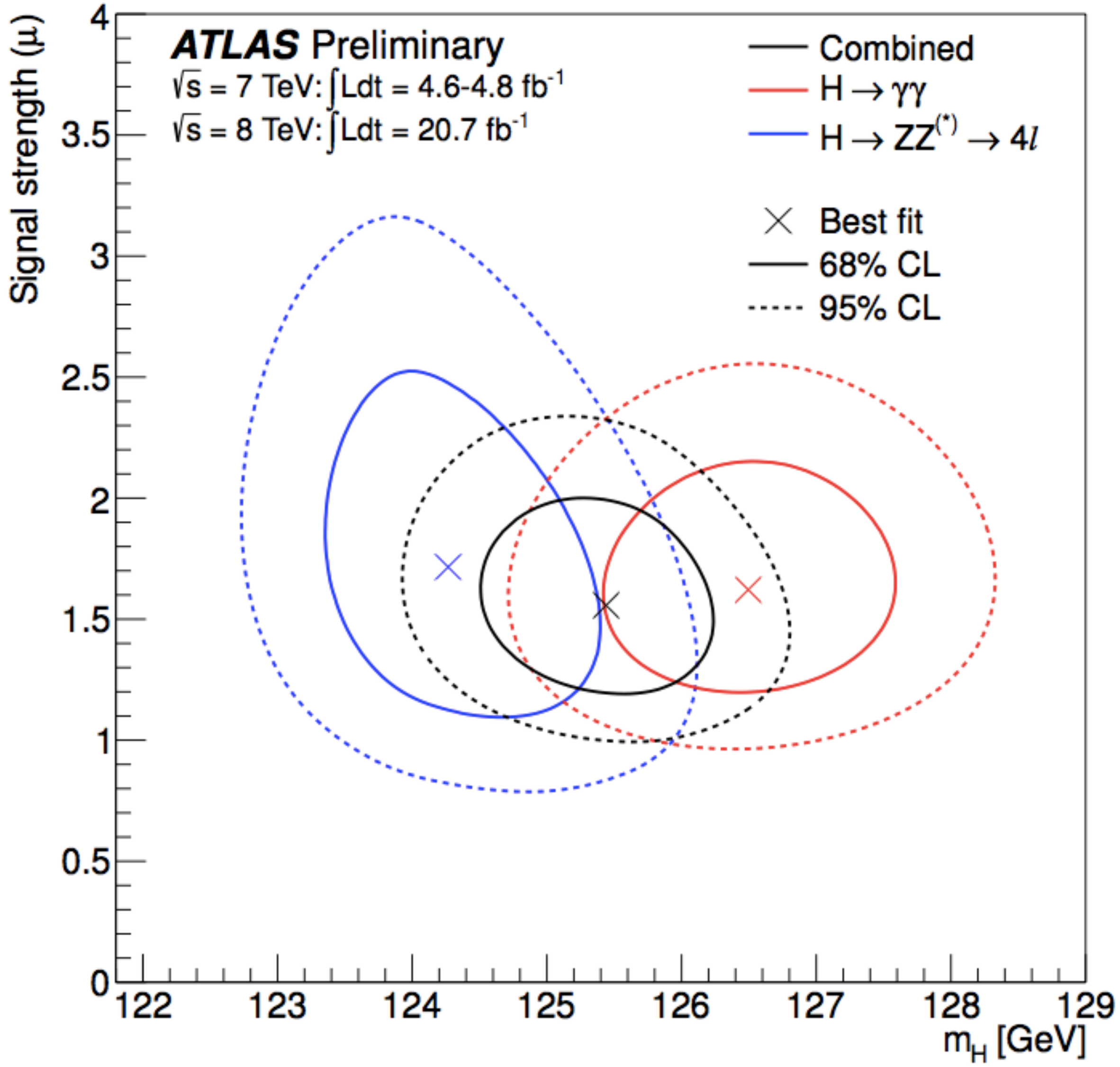
Higgs boson has been discovered!

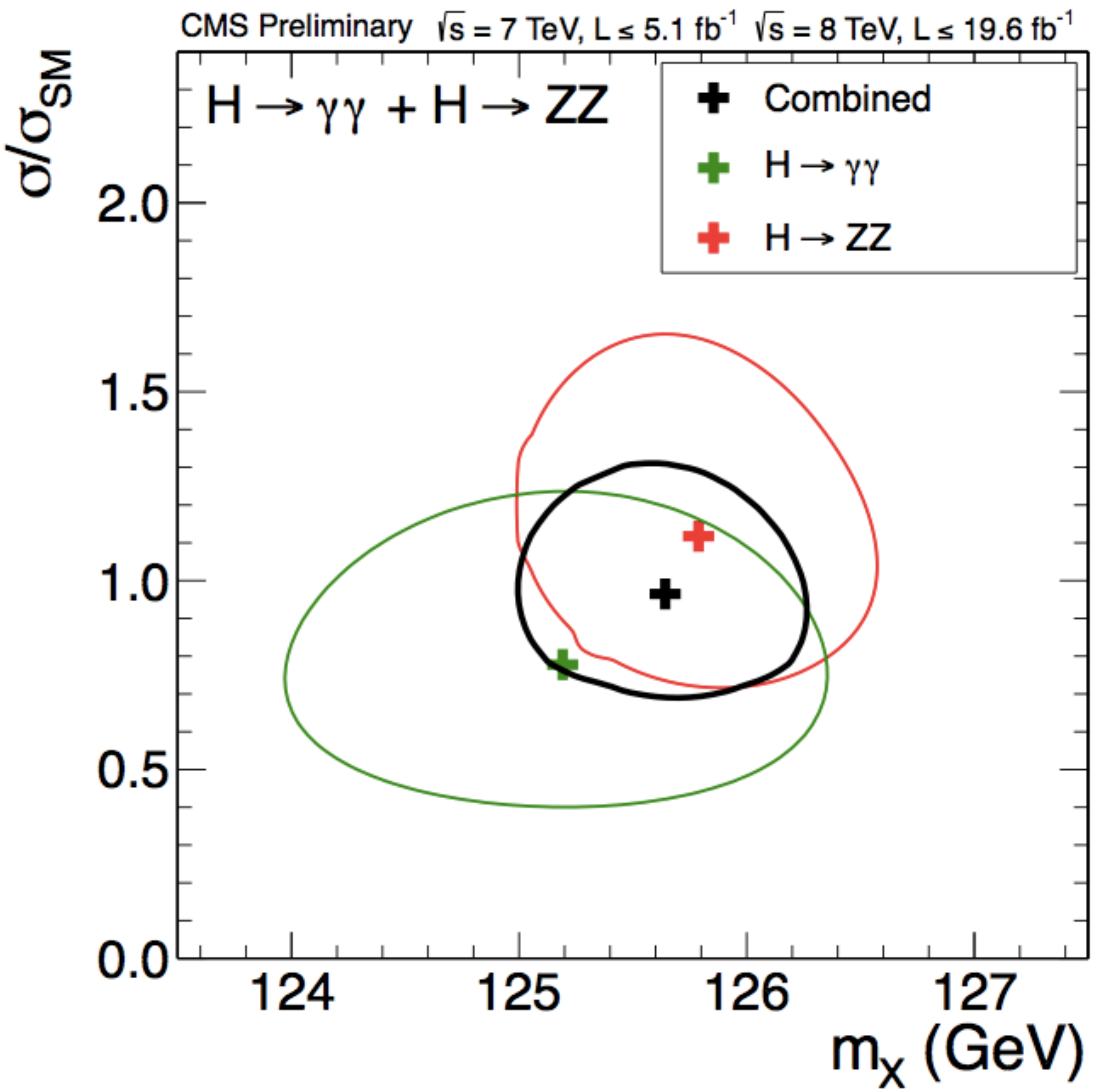
gallery

▶ Listen to François Englert (7:42)

▶ Interview transcript

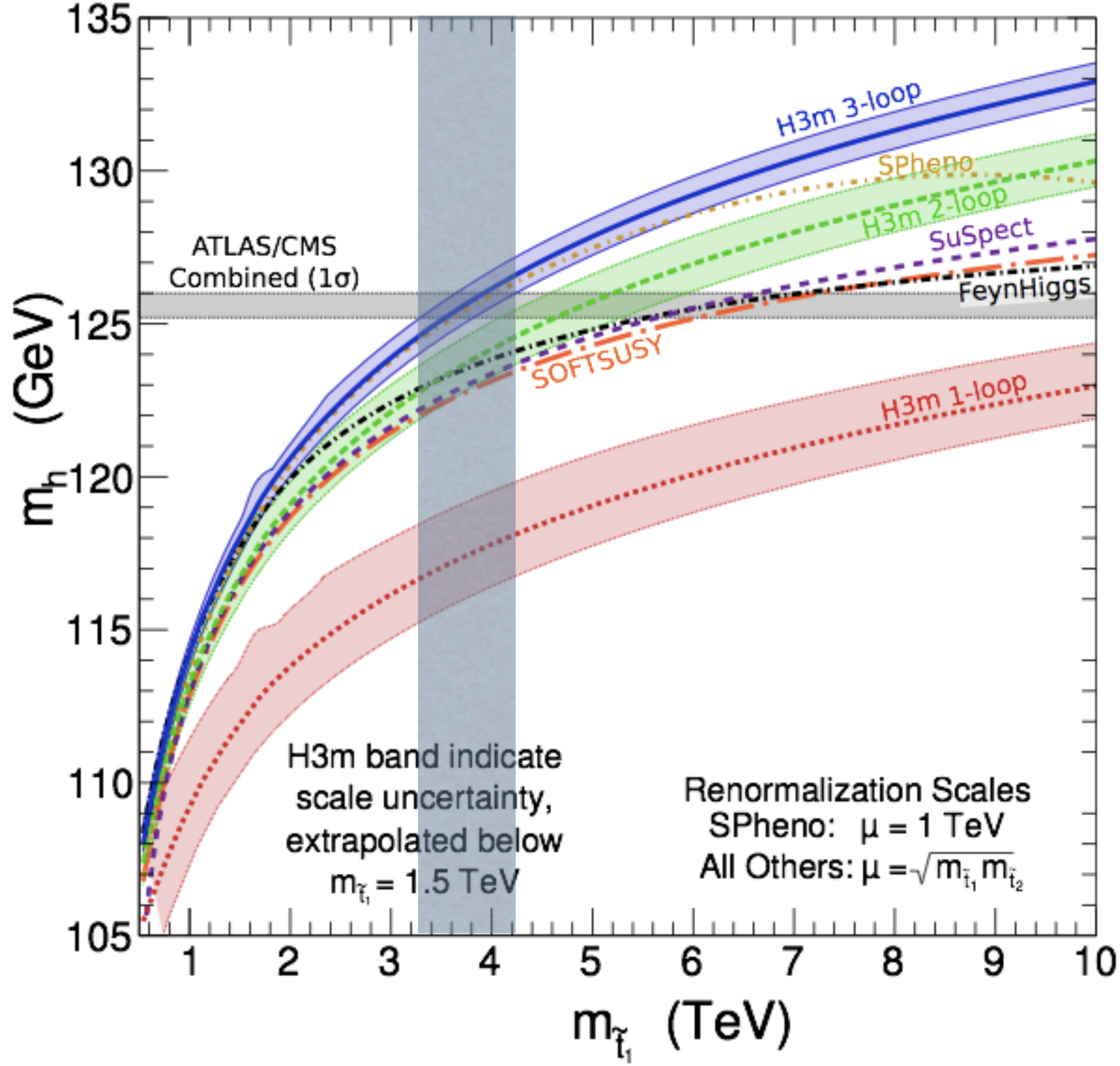
Higgs boson mass





Higgs boson mass ~125GeV

heavy stop(3-4TeV) can be consistent with the observation



@3-loop

$O(\alpha_t \alpha_S^2)$

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

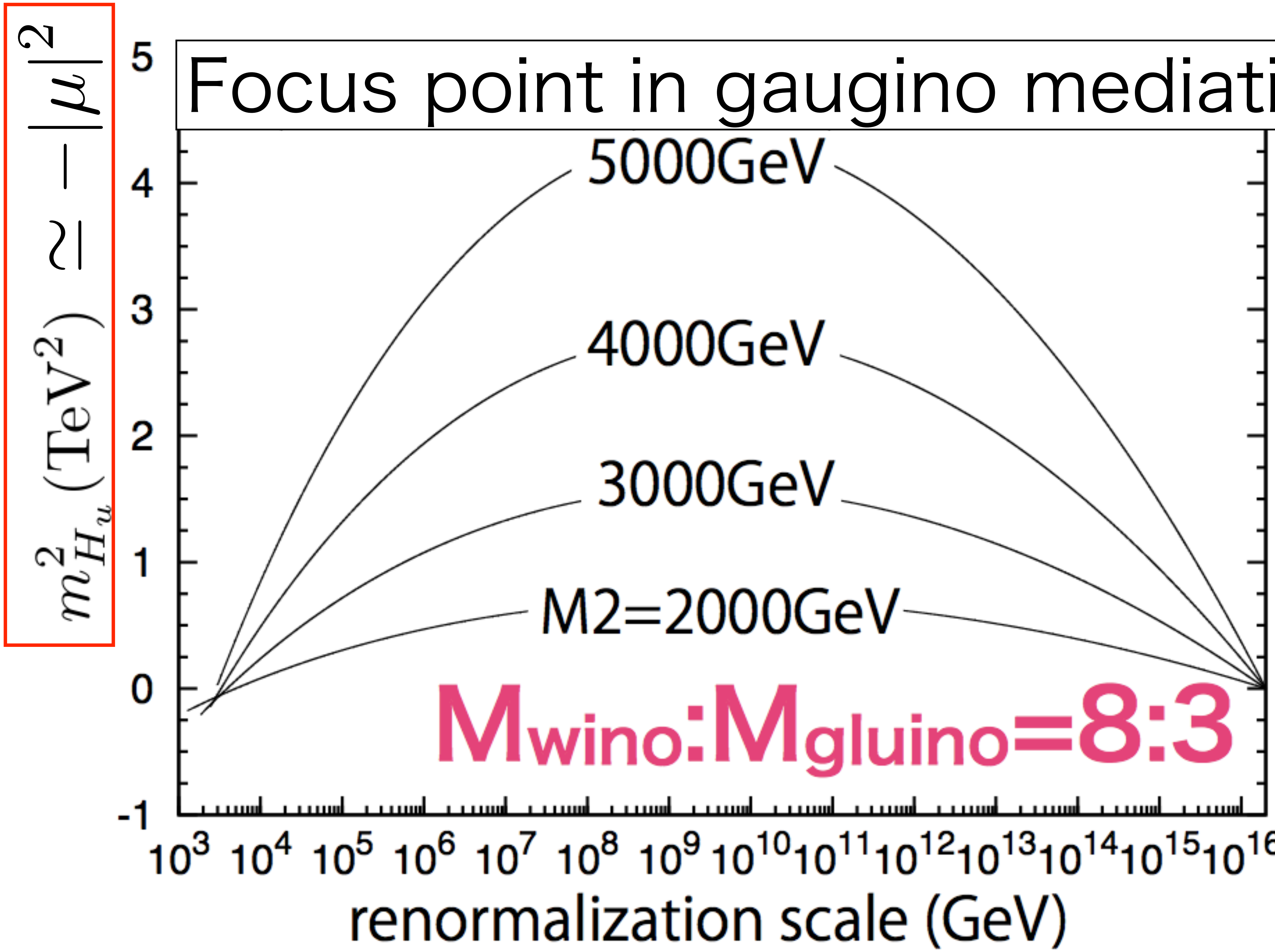
The H3m error corresponds to change of the renormalization scale from Ms/2 to 2Ms

Light SUSY particles@ILC?

Light SUSY particles@ILC?

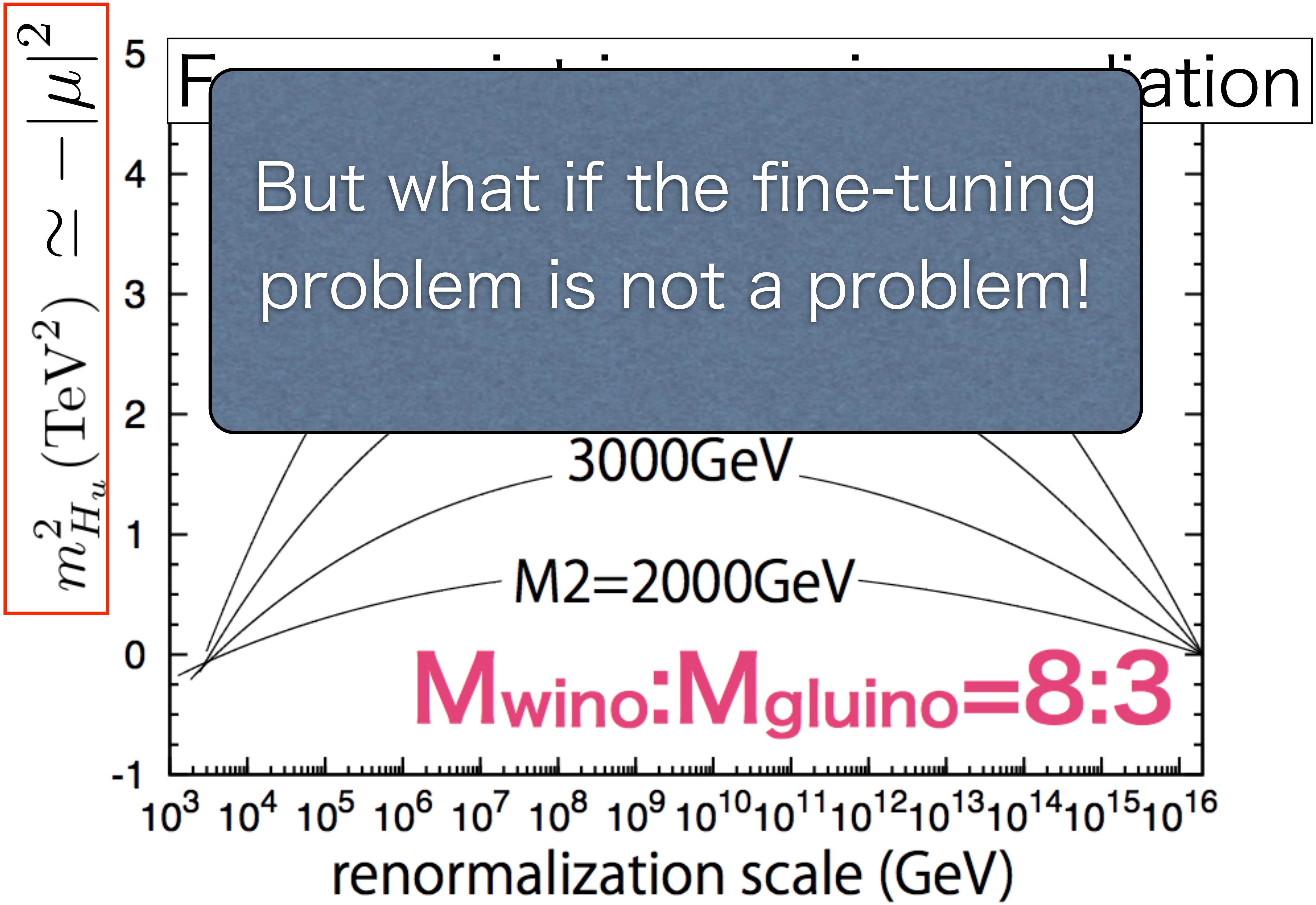
Light Higgsino ⇐ Fine-tuning problem

If the model has a focus point behavior



The Higgsino of O(100)GeV can be observed

If the model has a focus point behavior



The Higgsino of O(100)GeV can be observed

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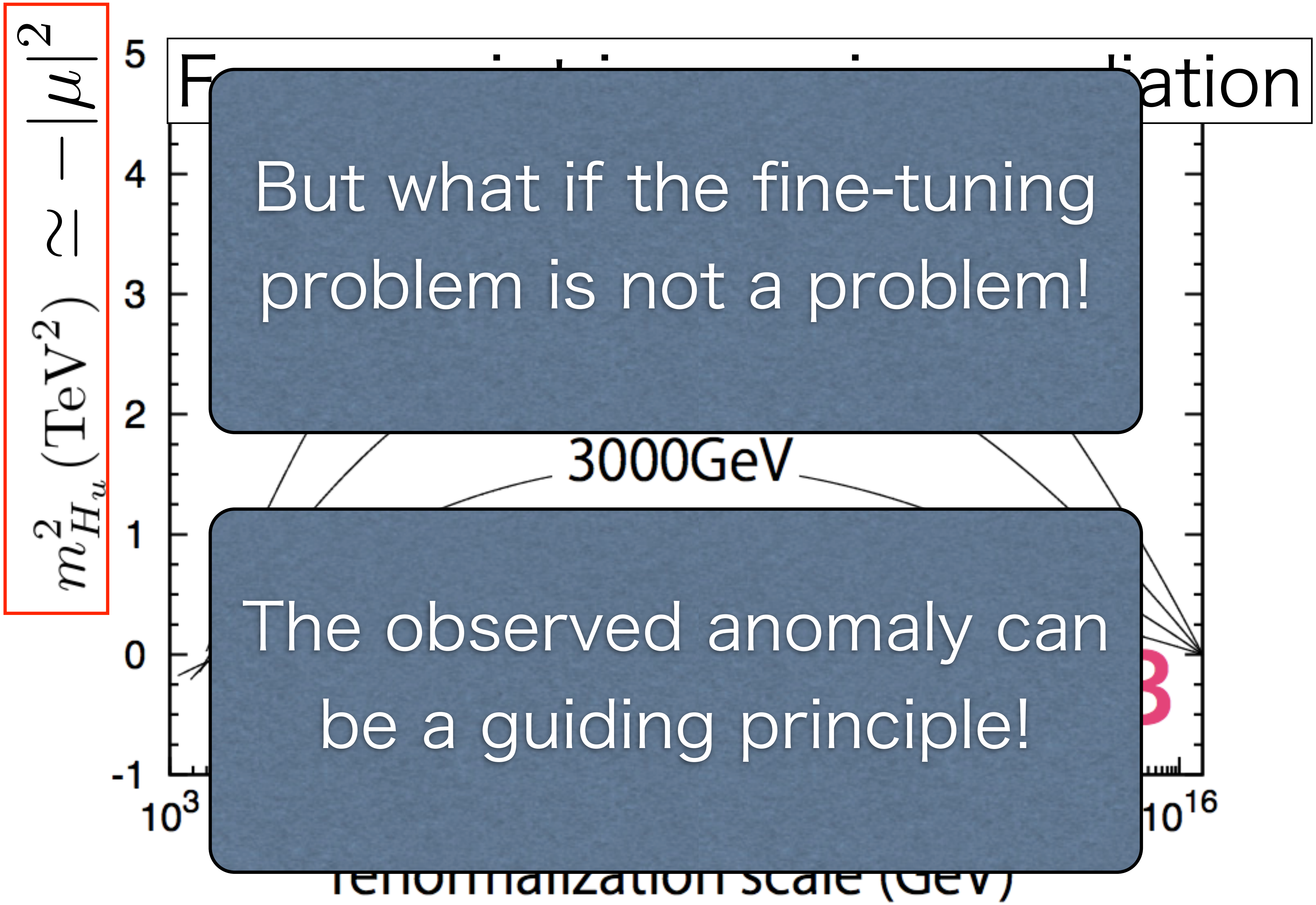
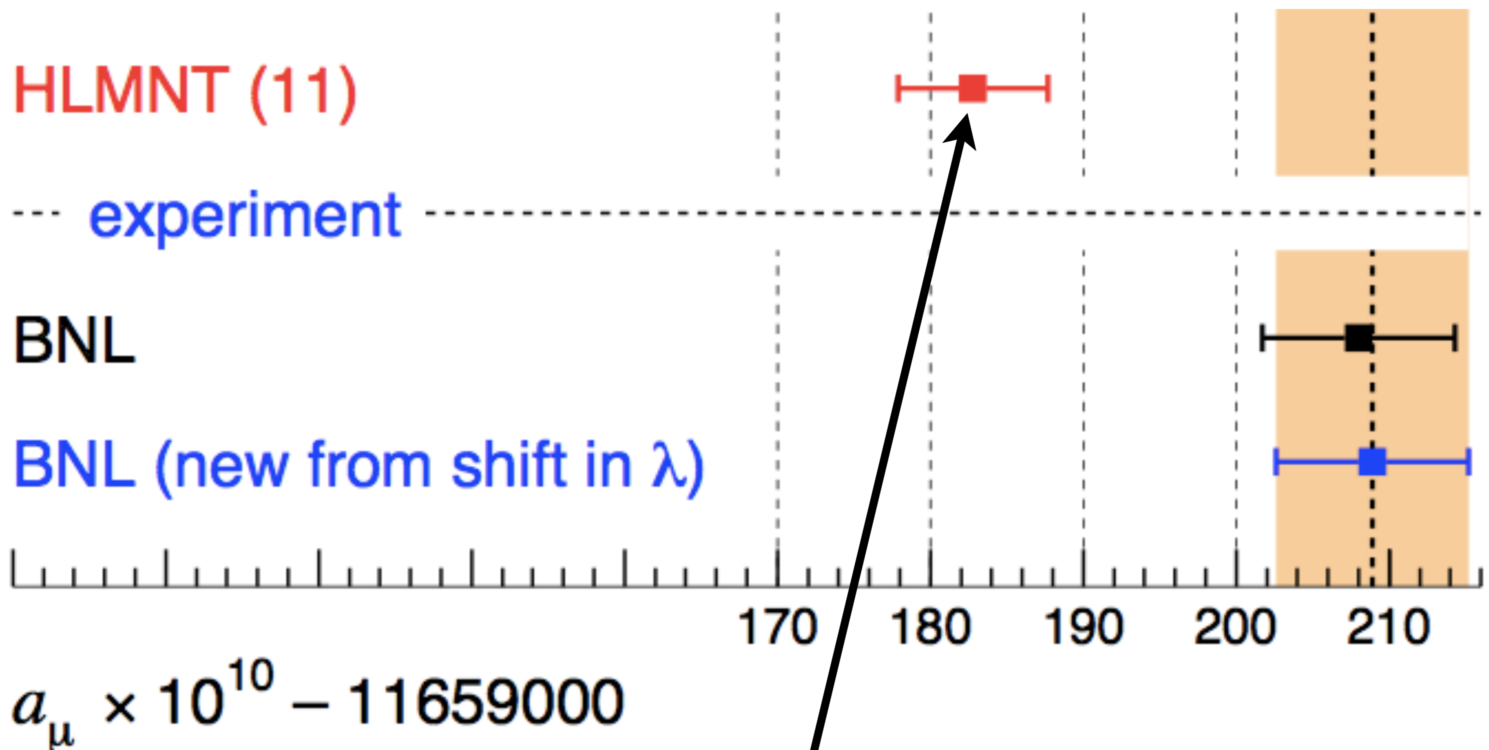


But what if the fine-tuning problem is not a problem!

The observed anomaly can be a guiding principle!

The Higgsino of O(100)GeV can be observed

Muon g-2 anomaly



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

>3σ deviation from SM prediction!

SM value

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

$$V(\vec{x}) = -\vec{\mu}\cdot\vec{B}(\vec{x}) \qquad \vec{\mu} = g\left(\frac{e}{2m_\mu}\right)\vec{S}$$

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

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

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

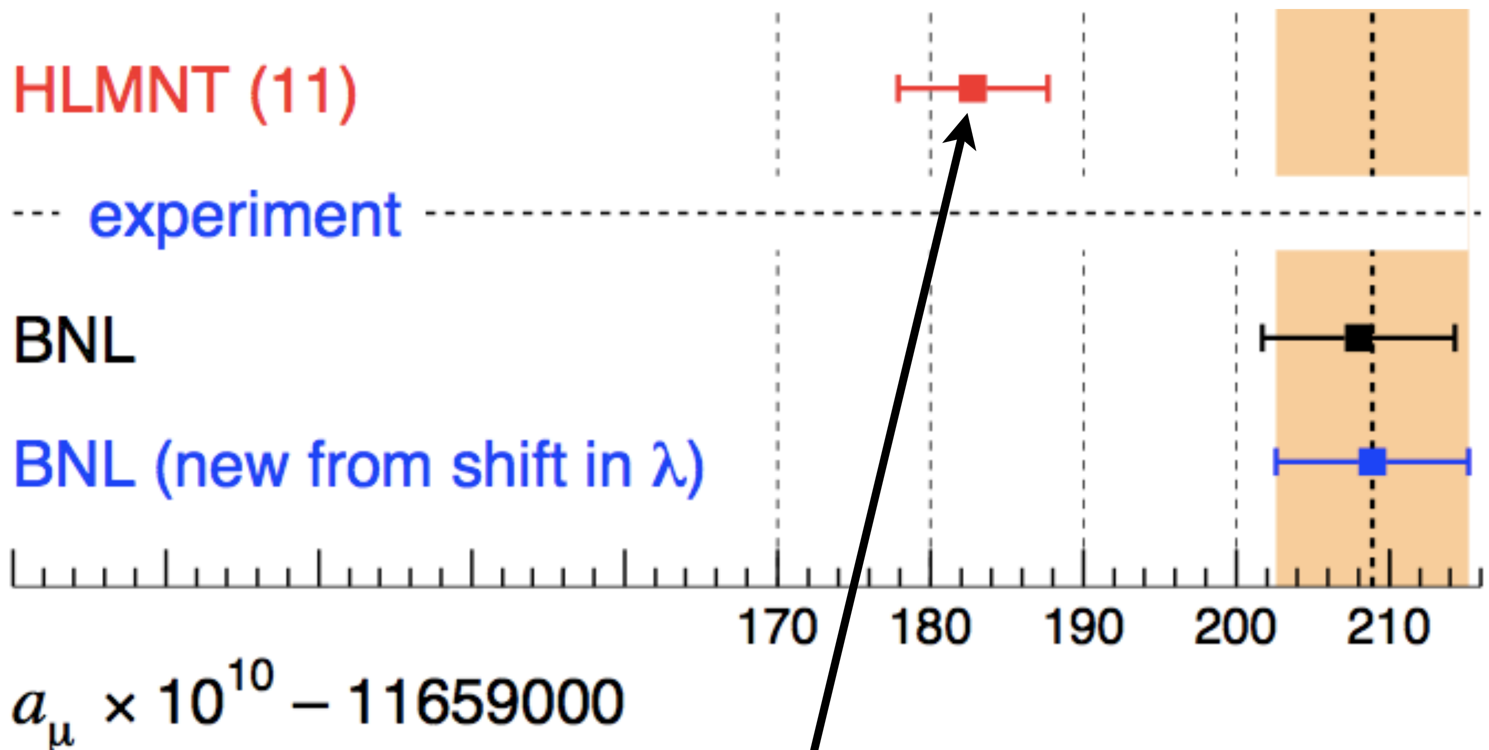
New coupling

Mass scale of new physics

We need O(100)GeV new particles.

Accessible at the ILC!

Muon g-2 anomaly



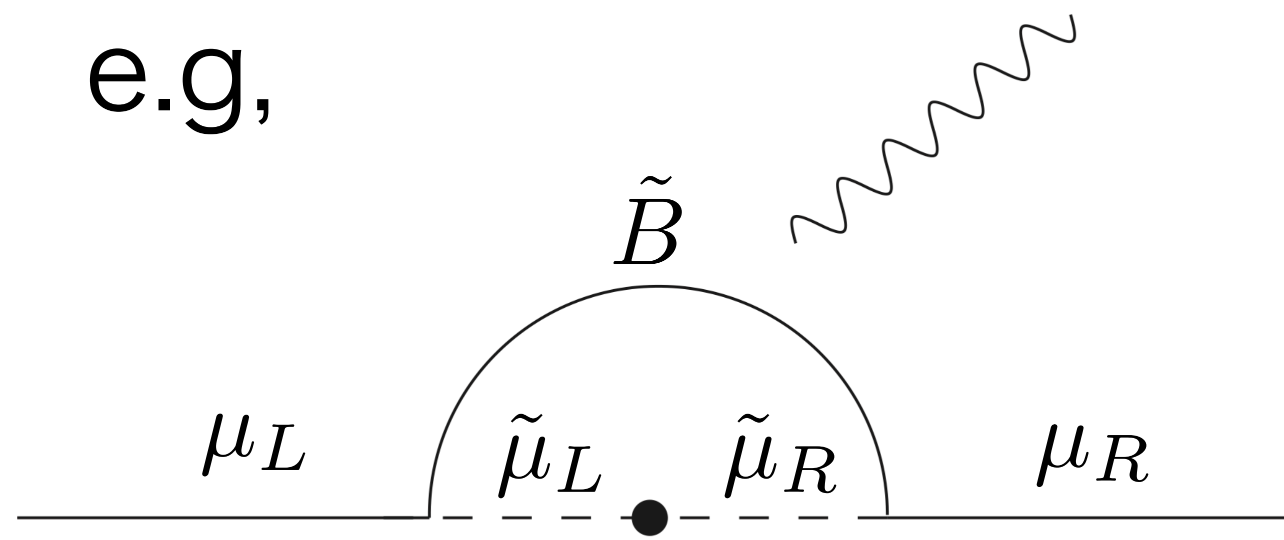
[Hagiwara, Liao, Martin, Nomura, Teubner, J.Phys. G38 (2011) 085003]

>3σ deviation from SM prediction!

SM value

light non-colored SUSY particle can explain this deviation

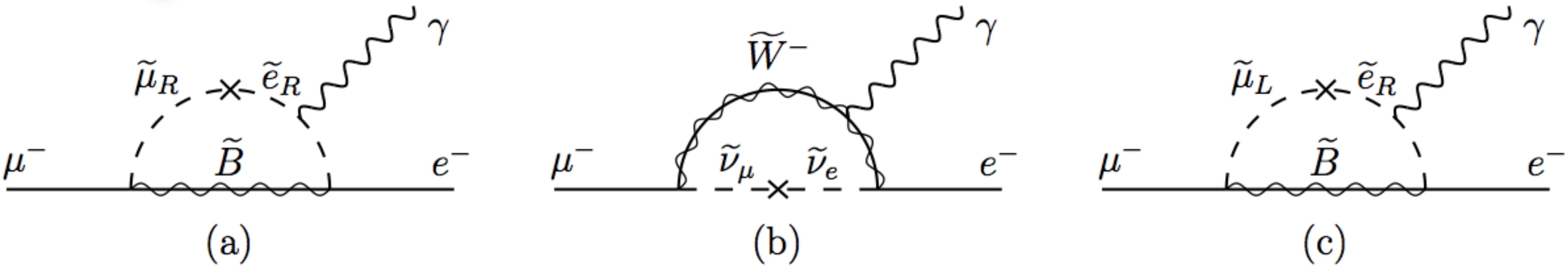
e.g,



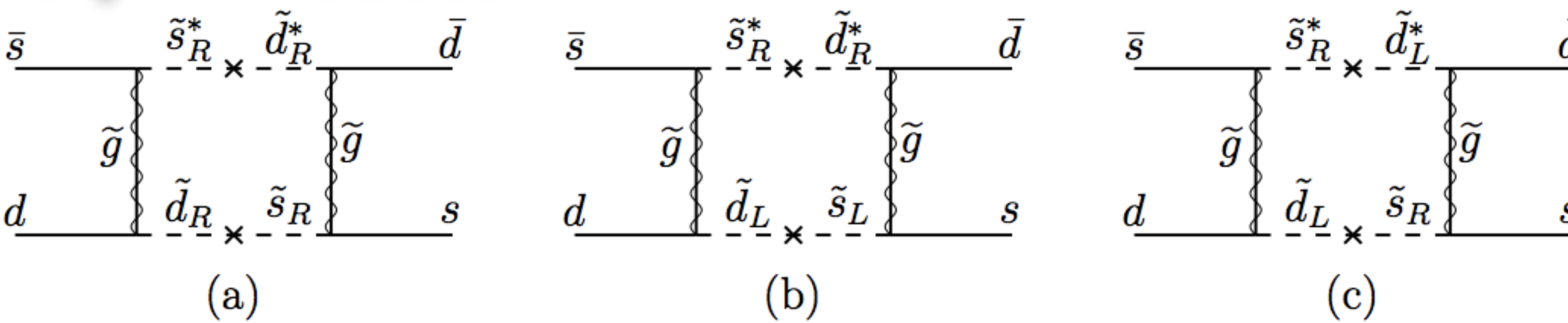
$\sim m_\mu \mu \tan\beta$

Sever constraints from flavor violating processes

slepton sector



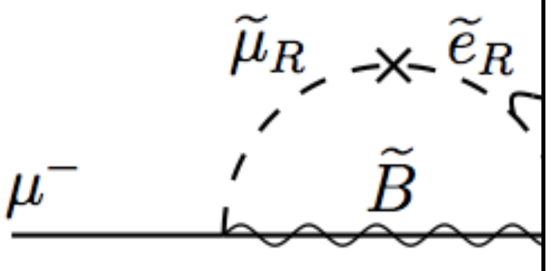
squark sector



We can not take them to be light without thinking

Sever constraints from flavor violating processes

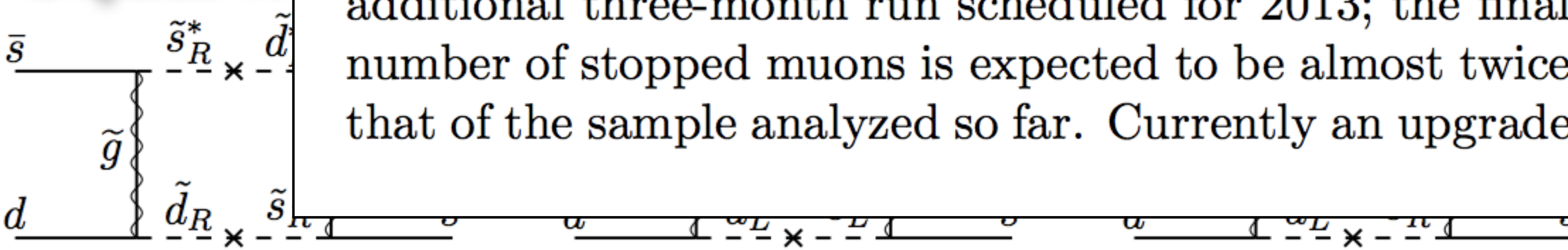
slepton sector ~10TeV for O(1) mixing



(a)

In conclusion the MEG experiment has so established the most stringent upper limit to date on the branching ratio of the $\mu^+ \to e^+\gamma$ decay, $\mathcal{B} < 5.7 \times 10^{-13}$ at 90% C.L. using data collected between 2009 and 2011, which improves the previous best upper limit by a factor of four. Further data have also been acquired in 2012 with an additional three-month run scheduled for 2013; the final number of stopped muons is expected to be almost twice that of the sample analyzed so far. Currently an upgrade

squark

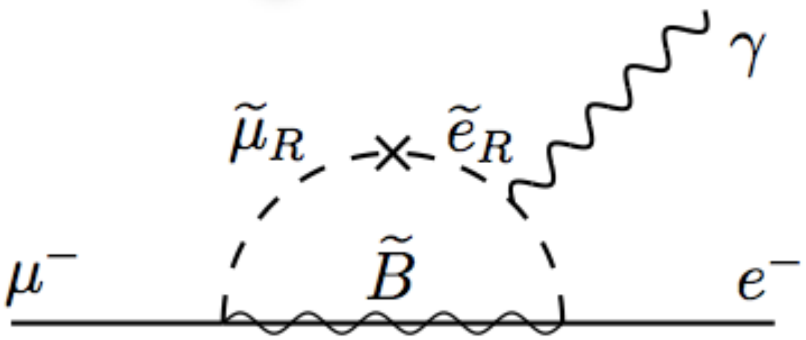


(a) (b) (c)

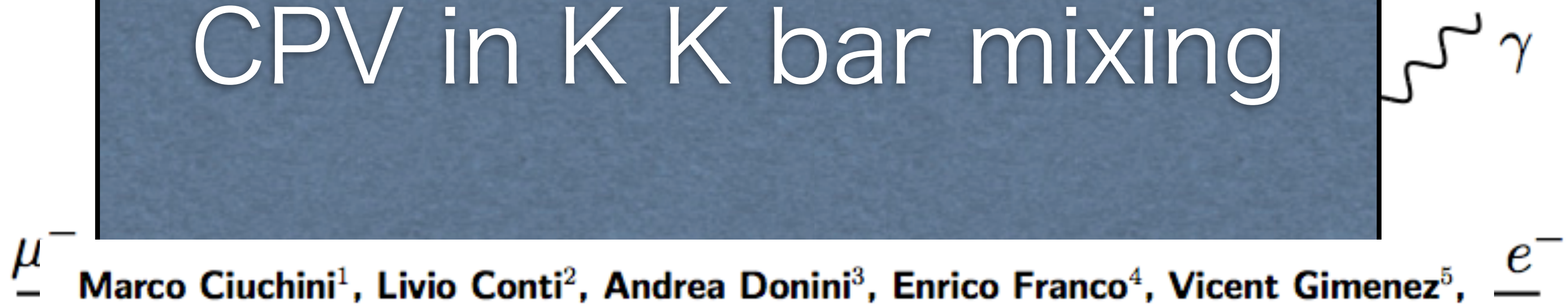
We can not take them to be light without thinking

Sever constraints from flavor violating processes

slepton sector



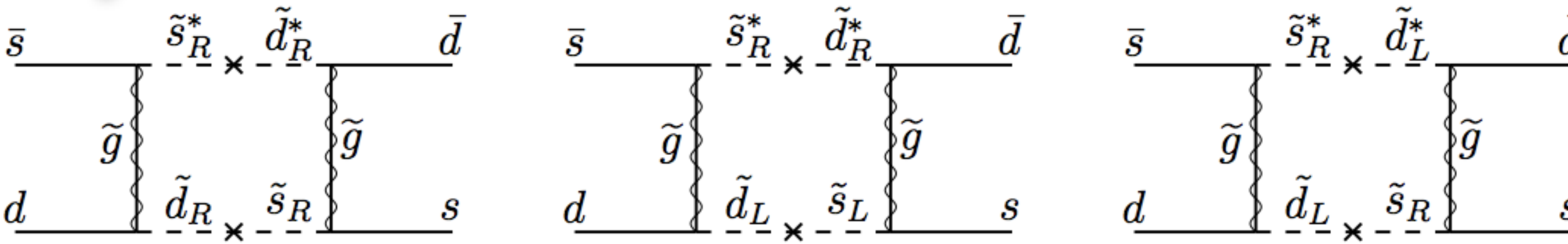
(a)



CPV in K K bar mixing

Marco Ciuchini[1], Livio Conti[2], Andrea Donini[3], Enrico Franco[4], Vicent Gimenez[5], Leonardo Giusti[6], Vittorio Lubicz[1], Guido Martinelli[4], Antonio Masiero[7], Ignazio Scimemi[4], Luca Silvestrini[8], Mauro Talevi[9], Anastassios Vladikas[2] ,1998

squark sector ~1000TeV! for O(1) mixing



(a) (b) (c)

We can not take them to be light without thinking

What we should do?

Higgs boson
mass~125GeV

→

heavy colored
SUSY particles

What we should do?

Higgs boson mass~125GeV → **heavy** colored SUSY particles

Anomaly of the muon g-2 → **light** non-colored SUSY particles

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FCNC should be avoided

What we should do?

Higgs boson mass~125GeV → **heavy** colored SUSY particles

Anomaly of the muon g-2 → **light** non-colored SUSY particles

FCNC should be avoided

answer: colored and non-colored mass splitting in gauge mediation

Our model

Adjoint messenger gauge mediation model

Adjoint Messenger Model

$$
\begin{aligned}
W = &(M_8 + \lambda_8 F\theta^2)\mathrm{Tr}\Sigma_8^2 \\
&+(M_3 + \lambda_3 F\theta^2)\mathrm{Tr}\Sigma_3^2 \\
&+(M_5 + \lambda_5 F\theta^2)\Psi_5\Psi_{\bar{5}}
\end{aligned}
$$

No hyper charge

To give masses to right handed sleptons/bino

Octet/triplet messenger does not give masses to the bino and right handed sleptons.

Gauge Coupling Unification

With MSSM matter contents, gauge coupling unification is satisfied. (Of course!)

Even if we include color octet and SU(2) triplet, the gauge coupling unified non-trivially

Σ_8 :SU(3) octet Σ_3 :SU(2) triplet

Renormalization group equations change

$$\alpha_1^{-1}(M_{\rm str}) = \alpha_1^{-1}(m_{\rm SUSY}) - \frac{b_1}{2\pi}\ln\frac{M_{\rm str}}{m_{\rm SUSY}},$$

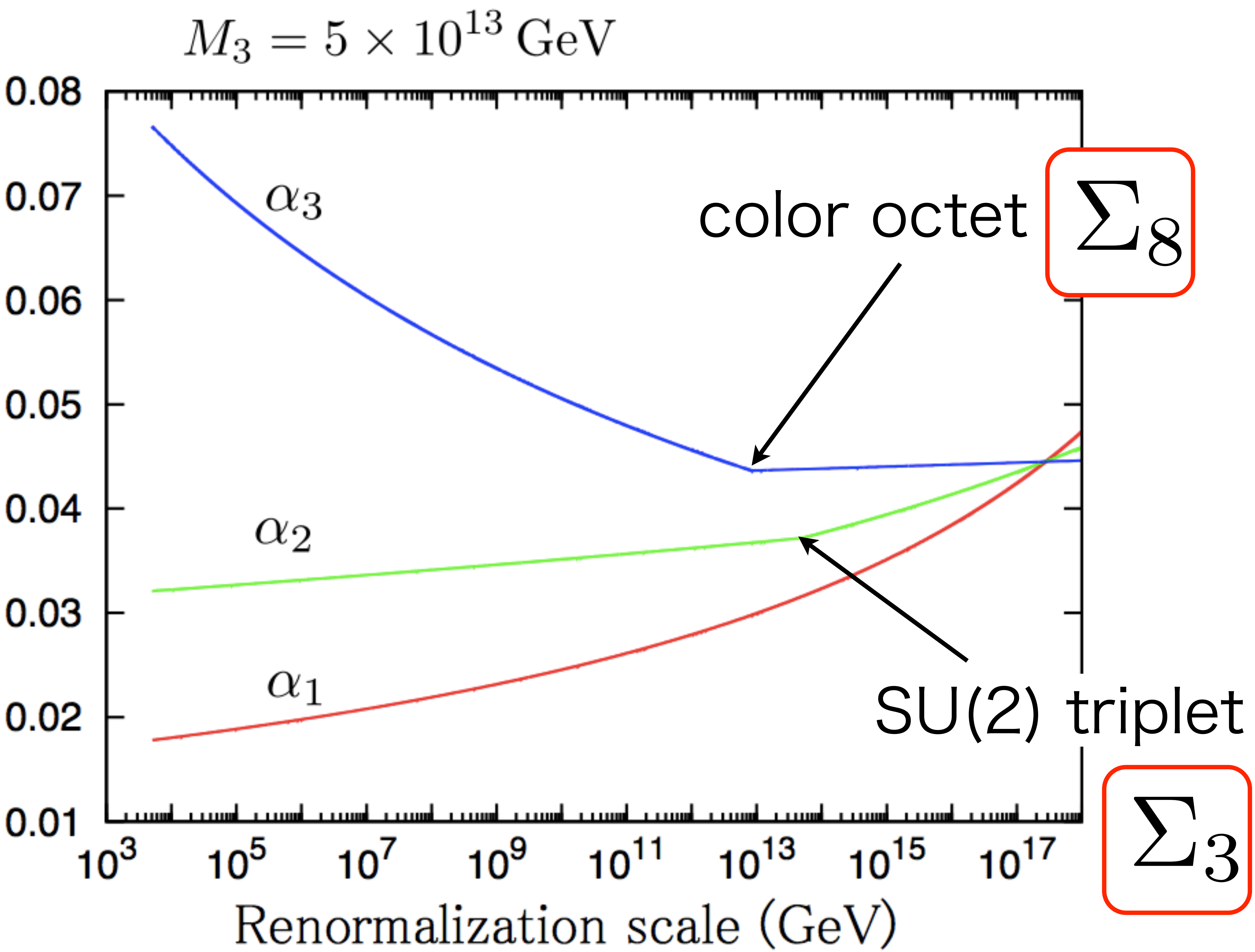
$$\alpha_2^{-1}(M_{\rm str}) = \alpha_2^{-1}(m_{\rm SUSY}) - \frac{b_2}{2\pi}\ln\frac{M_{\rm str}}{m_{\rm SUSY}} - \frac{2}{2\pi}\ln\frac{M_{\rm str}}{M_3}$$

$$\alpha_3^{-1}(M_{\rm str}) = \alpha_3^{-1}(m_{\rm SUSY}) - \frac{b_3}{2\pi}\ln\frac{M_{\rm str}}{m_{\rm SUSY}} - \frac{3}{2\pi}\ln\frac{M_{\rm str}}{M_8}$$

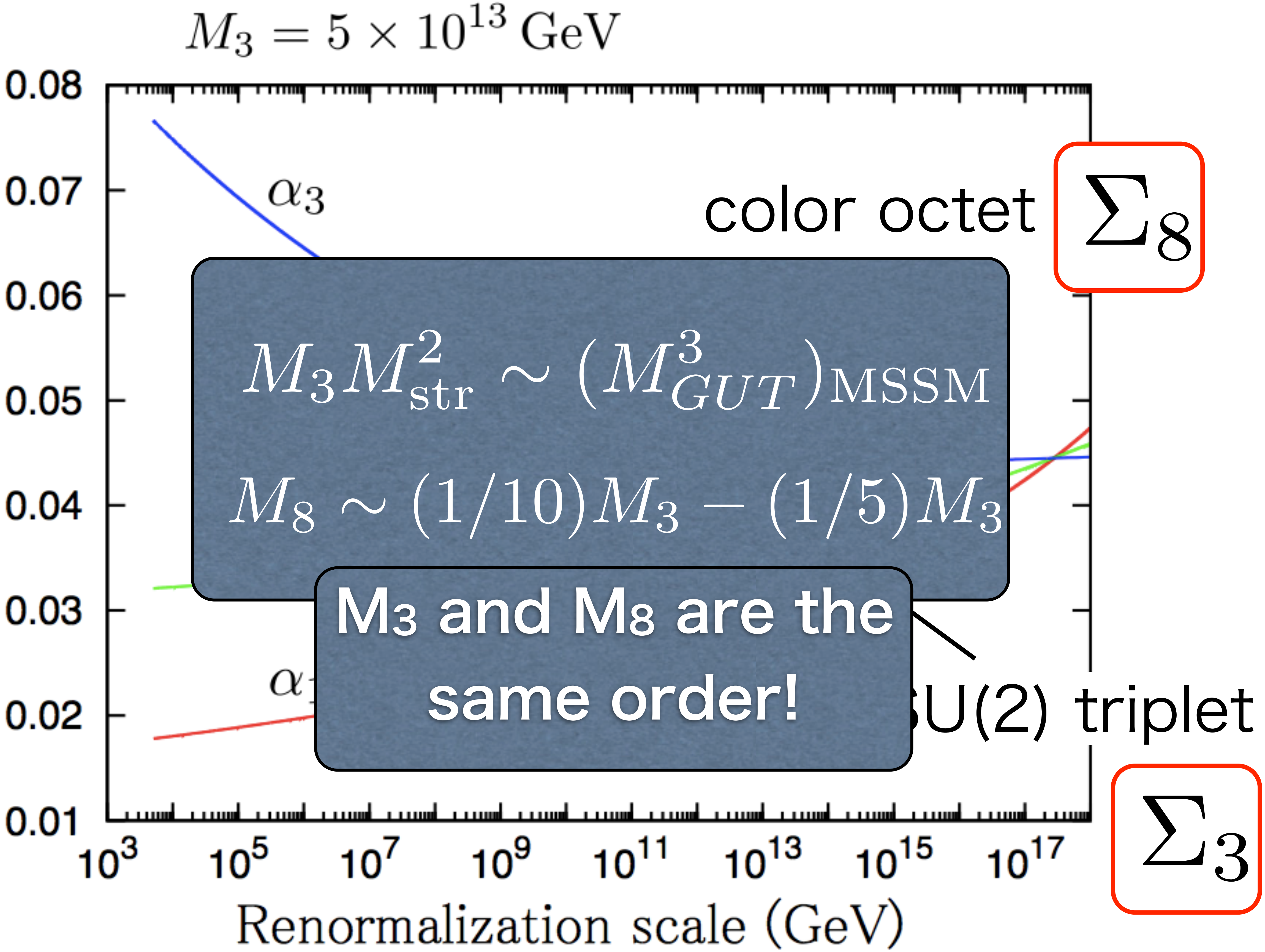
This part

@1-loop level

Two-loop RGE analysis



Two-loop RGE analysis



$$M_3 M_{\rm str}^2 \sim (M_{GUT}^3)_{\rm MSSM}$$

$$M_8 \sim (1/10)M_3 - (1/5)M_3$$

M₃ and M₈ are the same order!

Adjoint Messenger Model

$$W = (M_8 + \lambda_8 F\theta^2)\mathrm{Tr}\Sigma_8^2$$
$$+(M_3 + \lambda_3 F\theta^2)\mathrm{Tr}\Sigma_3^2$$
$$+(M_5 + \lambda_5 F\theta^2)\Psi_5\Psi_{\bar{5}}$$

No hyper charge

To give masses to right handed sleptons/bino

Octet/triplet messenger does not give masses to the bino and right handed sleptons.

Gaugino mass

$$M_1 \simeq \frac{\alpha_1}{4\pi}\Lambda_5,\ M_2 \simeq \frac{\alpha_2}{4\pi}(2\Lambda_3+\Lambda_5),\ M_3 \simeq \frac{\alpha_3}{4\pi}(3\Lambda_8+\Lambda_5),$$

Sfermion mass

$$\begin{aligned}
m^2_{\tilde{Q}} &\simeq \frac{1}{8\pi^2}\left[\frac{4}{3}\alpha_3^2\left(3\Lambda_8^2+\Lambda_5^2\right)+\frac{3}{4}\alpha_2^2(2\Lambda_3^2+\Lambda_5^2)+\frac{1}{60}\alpha_1^2\Lambda_5^2\right] \\
m^2_{\tilde{\bar{U}}} &\simeq \frac{1}{8\pi^2}\left[\frac{4}{3}\alpha_3^2(3\Lambda_8^2+\Lambda_5^2)+\frac{4}{15}\alpha_1^2\Lambda_5^2\right], \\
m^2_{\tilde{\bar{D}}} &\simeq \frac{1}{8\pi^2}\left[\frac{4}{3}\alpha_3^2(3\Lambda_8^2+\Lambda_5^2)+\frac{1}{15}\alpha_1^2\Lambda_5^2\right], \\
m^2_{\tilde{L}} &= m^2_{H_u} = m^2_{H_d} \simeq \frac{1}{8\pi^2}\left[\frac{3}{4}\alpha_2^2(2\Lambda_3^2+\Lambda_5^2)+\frac{3}{20}\alpha_1^2\Lambda_5^2\right], \\
m^2_{\tilde{\bar{E}}} &\simeq \frac{1}{8\pi^2}\left[\frac{3}{5}\alpha_1^2\Lambda_5^2\right],
\end{aligned}$$

Definition

$$\Lambda_8 \equiv \frac{\lambda_8 F}{M_8},\ \Lambda_3 \equiv \frac{\lambda_3 F}{M_3},\ \Lambda_5 \equiv \frac{\lambda_5 F}{M_5}.$$

Gaugino mass

$$M_1 \simeq \qquad M_2 \simeq \frac{\alpha_2}{4\pi}(2\Lambda_3 \qquad), \; M_3 \simeq \frac{\alpha_3}{4\pi}(3\Lambda_8 \qquad),$$

Sfermion mass

$$m^2_{\tilde{Q}} \simeq \frac{1}{8\pi^2}\left[\frac{4}{3}\alpha_3^2\,(3\Lambda_8^2 \qquad + \frac{3}{4}\alpha_2^2(2\Lambda_3^2 \qquad \right]$$

$$m^2_{\tilde{\bar{U}}} \simeq \frac{1}{8\pi^2}\left[\frac{4}{3}\alpha_3^2(3\Lambda_8^2 \qquad \right],$$

$$m^2_{\tilde{\bar{D}}} \simeq \frac{1}{8\pi^2}\left[\frac{4}{3}\alpha_3^2(3\Lambda_8^2 \qquad \right],$$

$$m^2_{\tilde{L}} = m^2_{H_u} = m^2_{H_d} \simeq \frac{1}{8\pi^2}\left[\frac{3}{4}\alpha_2^2(2\Lambda_3^2 \qquad \right],$$

$$m^2_{\tilde{\bar{E}}} \simeq$$

Definition

$$\Lambda_8 \equiv \frac{\lambda_8 F}{M_8}, \; \Lambda_3 \equiv \frac{\lambda_3 F}{M_3}, \; \Lambda_5 \equiv \frac{\lambda_5 F}{M_5}.$$

Gaugino mass

$$M_1 \simeq \qquad M_2 \simeq \frac{\alpha_2}{4\pi}(2\Lambda_3 \qquad), \; M_3 \simeq \frac{\alpha_3}{4\pi}(3\Lambda_8 \qquad),$$

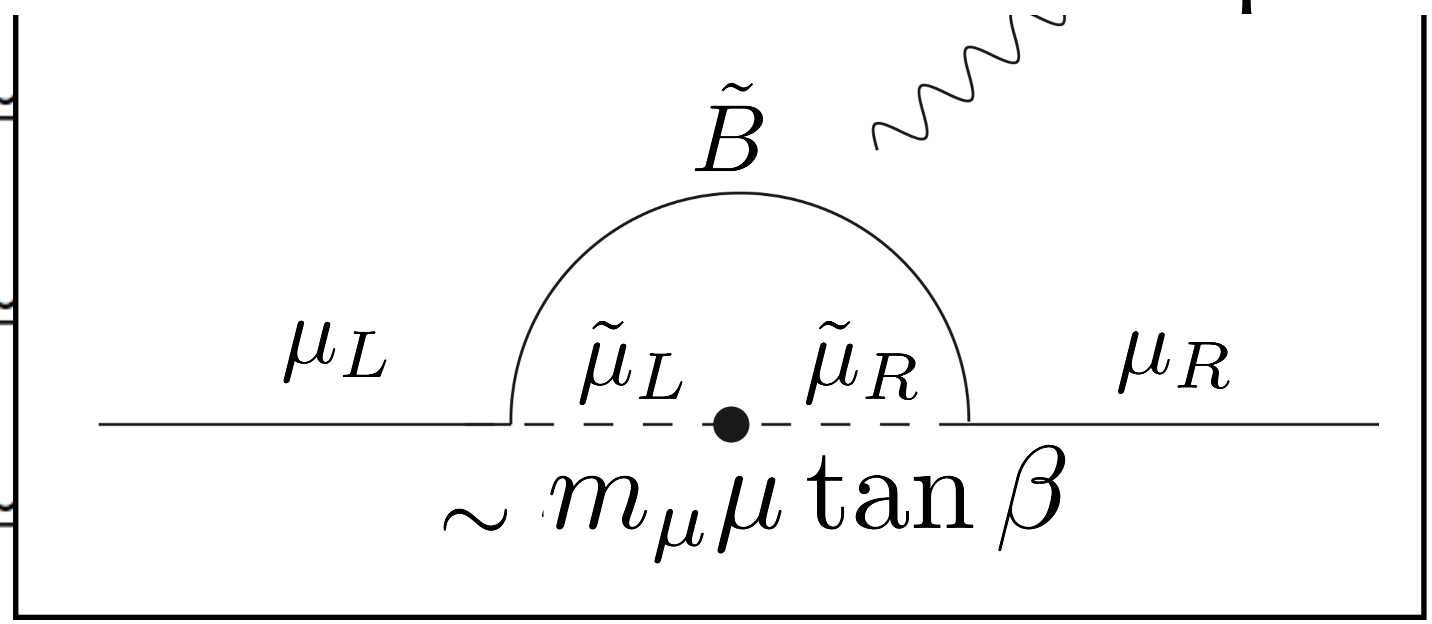
Sfermion mass

Bino contributions are important

$$m^2_{\tilde{Q}} \simeq \qquad]$$

$$m^2_{\tilde{\bar{U}}} \simeq$$

$$m^2_{\tilde{\bar{D}}} \simeq$$



$$m^2_{\tilde{L}} = m^2_{H_u} = m^2_{H_d} \simeq \frac{1}{8\pi^2}\left[\frac{3}{4}\alpha_2^2(2\Lambda_3^2 \qquad \right],$$

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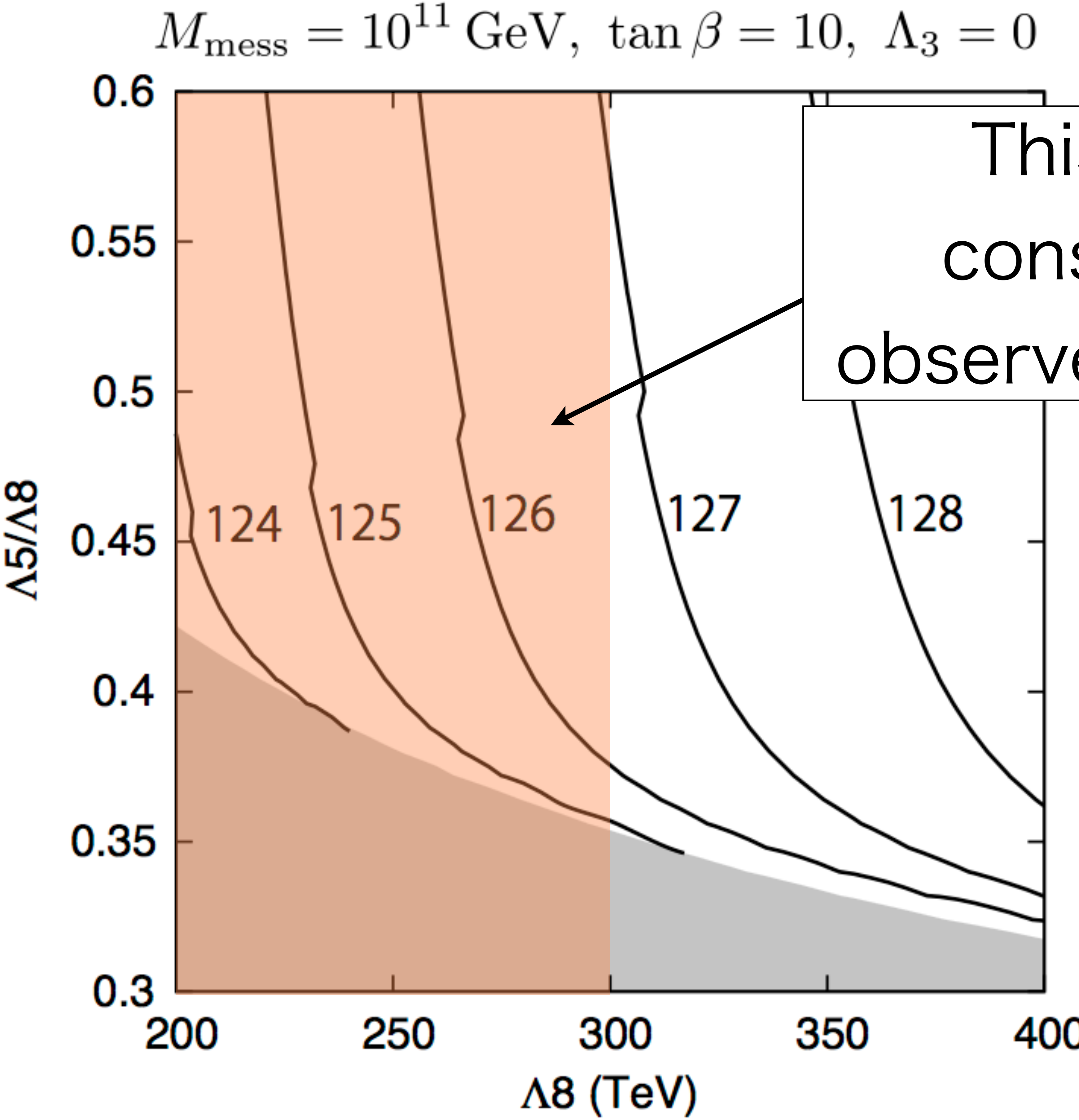
Definition $\Lambda_8 \equiv \frac{\lambda_8 F}{M_8}, \; \Lambda_3 \equiv \frac{\lambda_3 F}{M_3}, \; \Lambda_5 \equiv \frac{\lambda_5 F}{M_5}.$

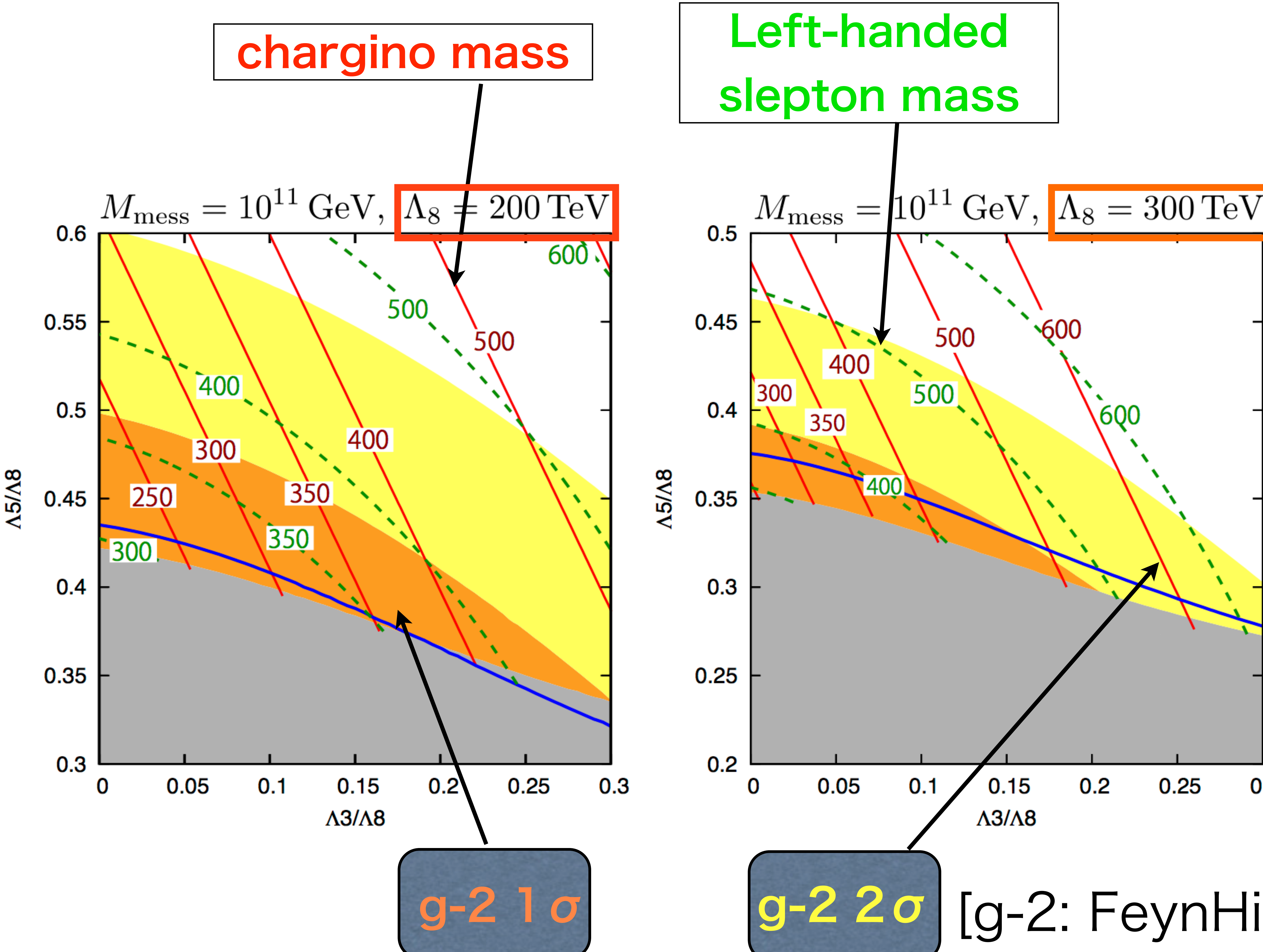
Results



This region is consistent with observed Higgs bosn

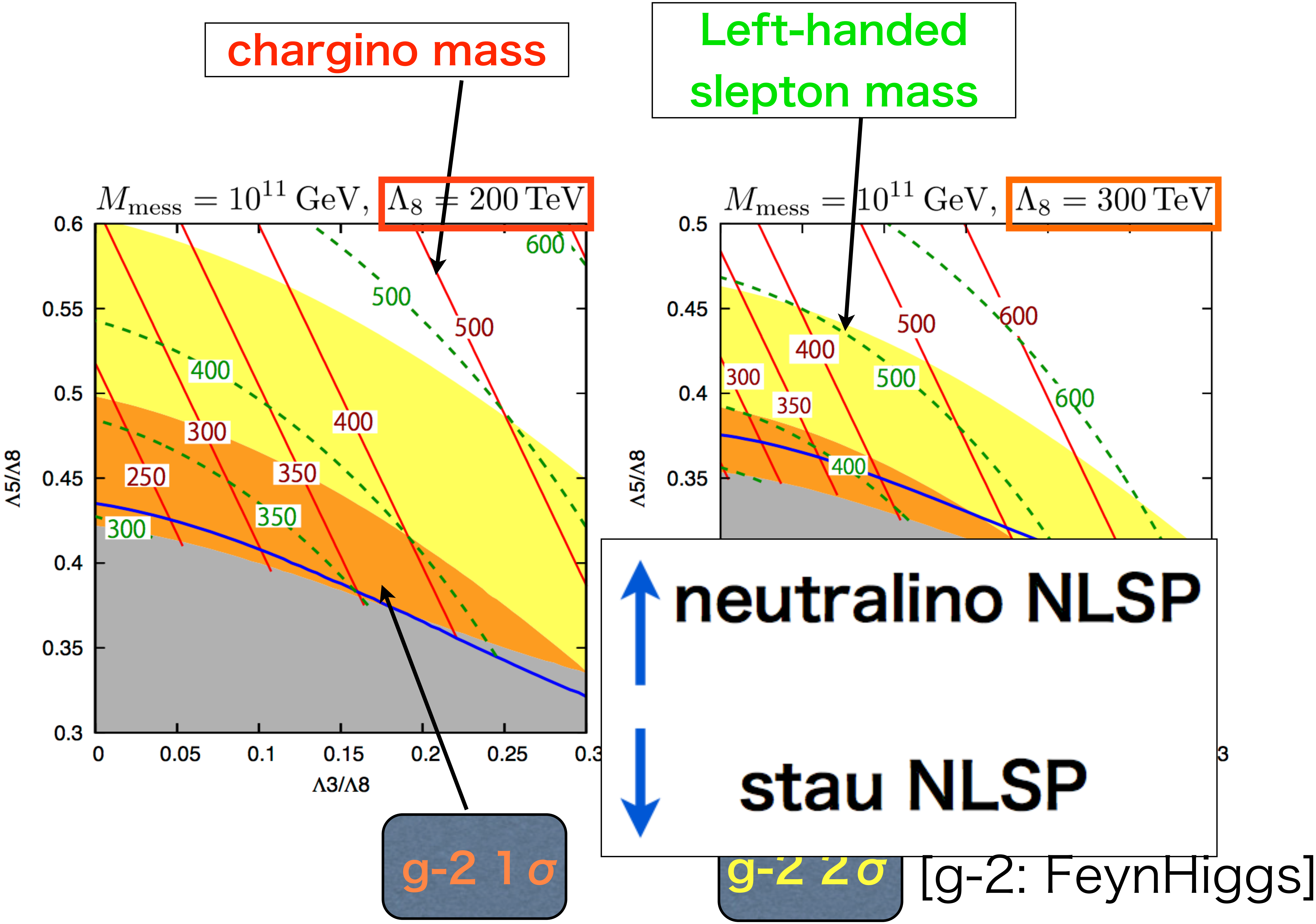
@3-loop with H3m

$m_{stop} \sim 3.6 - 5.1\ \mathrm{TeV}$



[g-2: FeynHiggs]

The stau NLSP needs to be heavier than 340GeV



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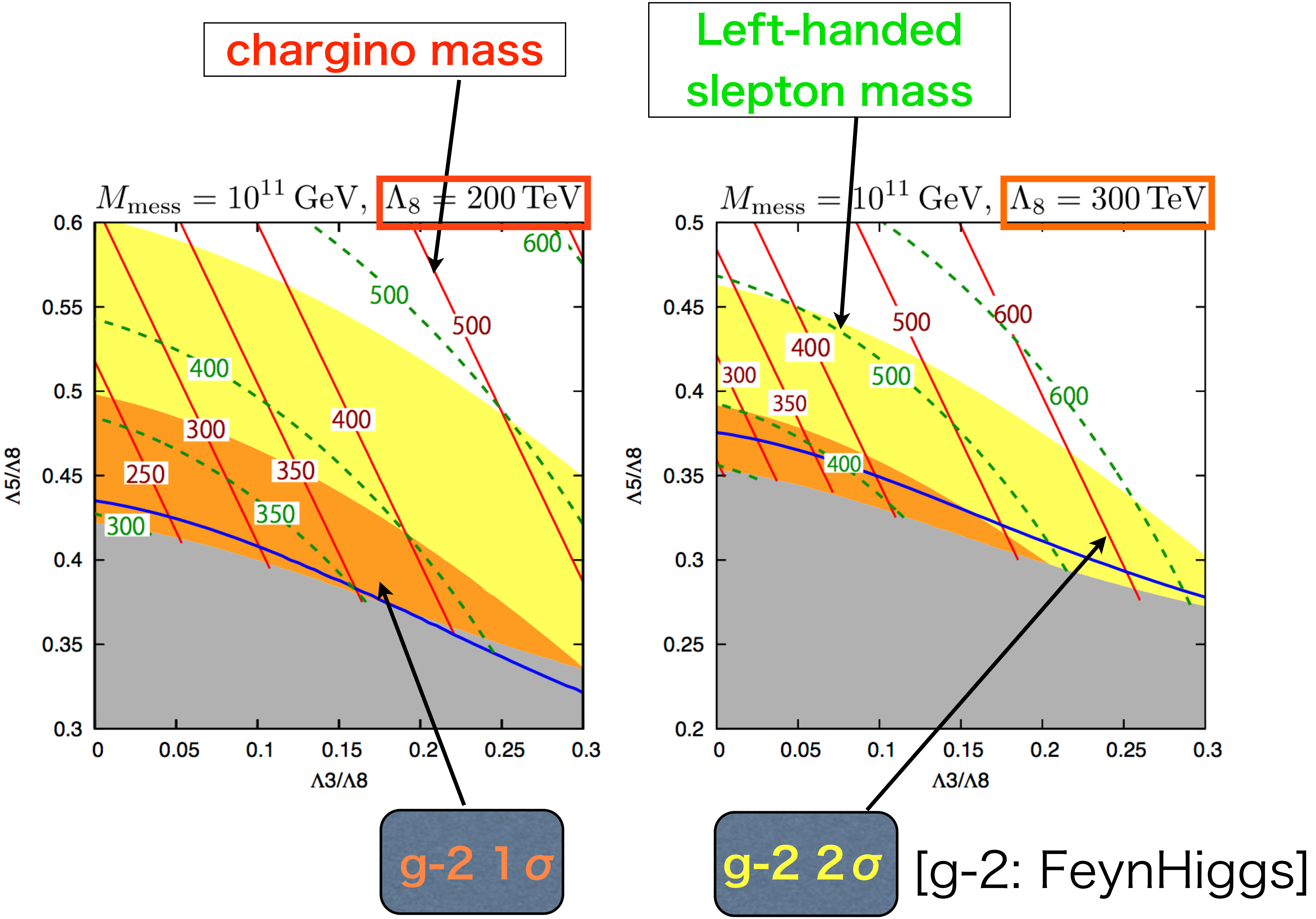


The stau NLSP needs to be heavier than 340GeV

LHC results constrain on the electroweak production modes quite severely

sleptons

$$\tilde{l}_L^* \tilde{l}_L \to l^+ l^- 2\chi_1^0$$

$$\tilde{l}_R^* \tilde{l}_R \to l^+ l^- 2\chi_1^0$$

Wino

$$\chi_1^\pm \chi_2^0 \to (3l + \nu) 2\chi_1^0$$

(tau dominated)

Some of the parameter space is exclude already

$$M_{\rm wino} \gtrsim 300 - 350\,{\rm GeV}$$

(vacuum stability bound of the stau is OK!)

Λ_3/Λ_8	0.17	Λ_3/Λ_8	0.11
Λ_5/Λ_8	0.41	Λ_5/Λ_8	0.35
Λ_8	200 TeV	[illegible]	300 TeV
$M_{\rm mess}$	10^{11} GeV	[illegible]	10^{11} GeV
$\tan\beta$	10	[illegible]	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}
$m_{\rm gluino}$	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

ILC!

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

Comments on Cosmology

Gravitino problem

Thermally produced NLSP decays into the gravitino and a SM particle

e.g.

bino -> photon or Z + gravitino

If the NLSP decays during/after the BBN era (~0.01s-100s), the successful BBN prediction may be destroyed!

Life-time of NLSP

Bino:

$$\Gamma(\tilde{B} \to \psi_{3/2}\gamma) \simeq \frac{\cos^2\theta_W M_{\tilde{B}}^5}{48\pi M_{\rm PL}^2 m_{3/2}^2}$$

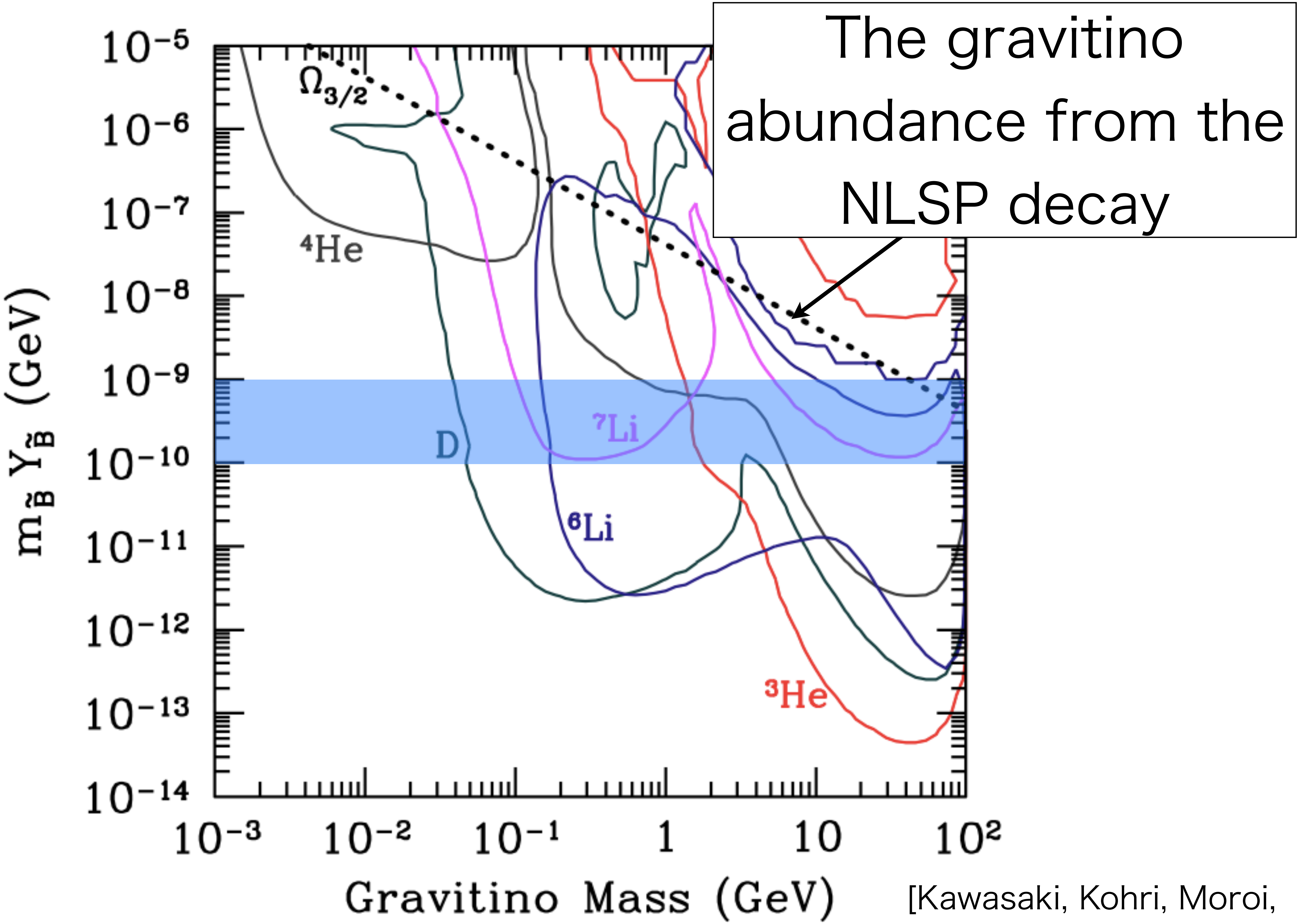
$$\Gamma(\tilde{B} \to \psi_{3/2}Z) \simeq \frac{\sin^2\theta_W M_{\tilde{B}}^5}{48\pi M_{\rm PL}^2 m_{3/2}^2}$$

~100s for 150GeV Bino and 0.1GeV gravitino

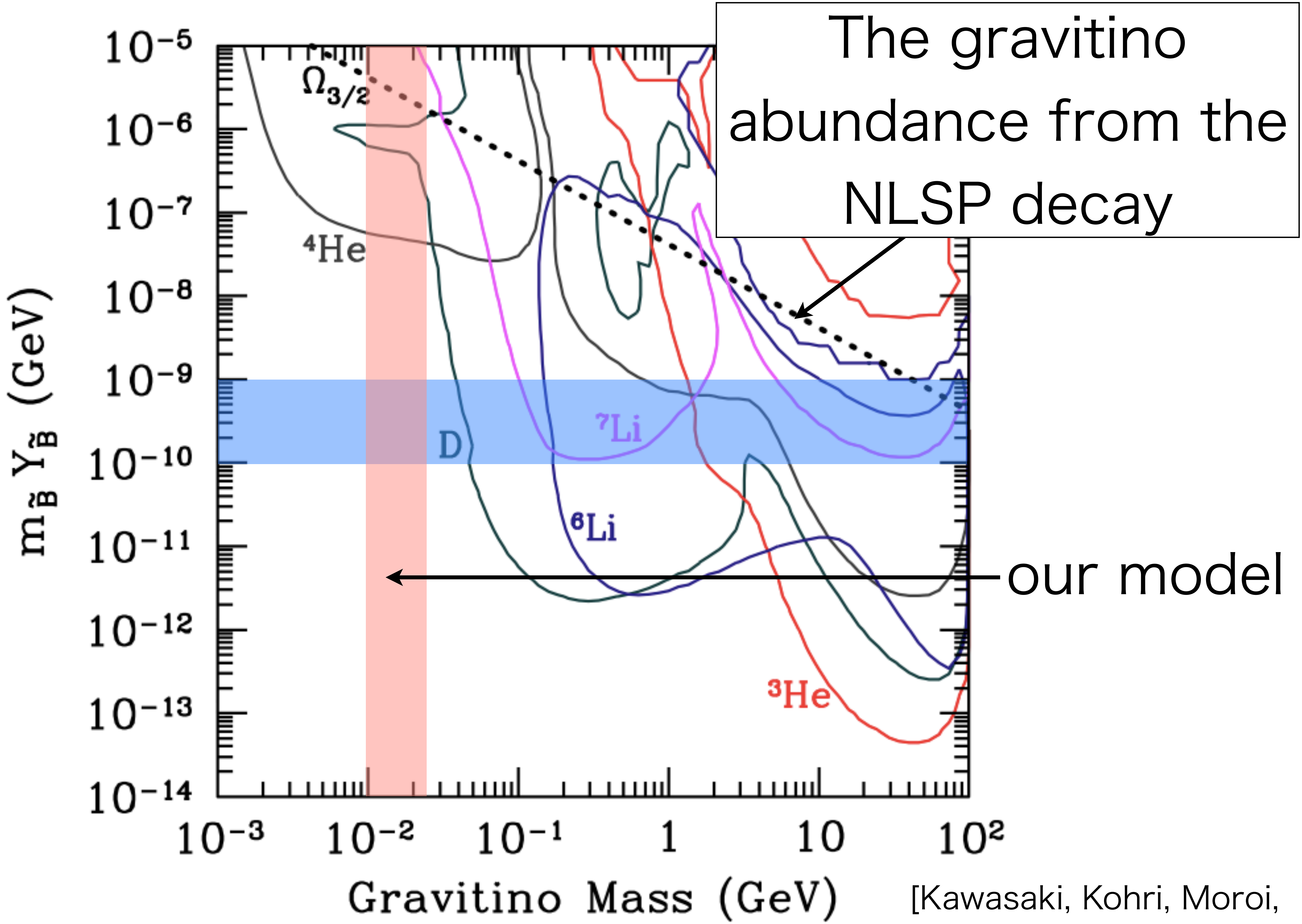
$c\tau \sim 10^{10}$ m Stable at the collider scale

The BBN prediction constrains the abundance of the NLSP and the gravitino mass

Roughly, if the gravitino mass is larger than about 0.1GeV, then it becomes problematic.



[Kawasaki, Kohri, Moroi, Yotsuyanagi, 2008]



[Kawasaki, Kohri, Moroi, Yotsuyanagi, 2008]

Summary

Only few viable models can explain

Higgs boson mass, muon g-2 anomaly, LHC results

Consistent with cosmological gravitino problem

Light sleptons can be observed at the ILC!