Jan. 10th, 2017@Tokyo Univ.

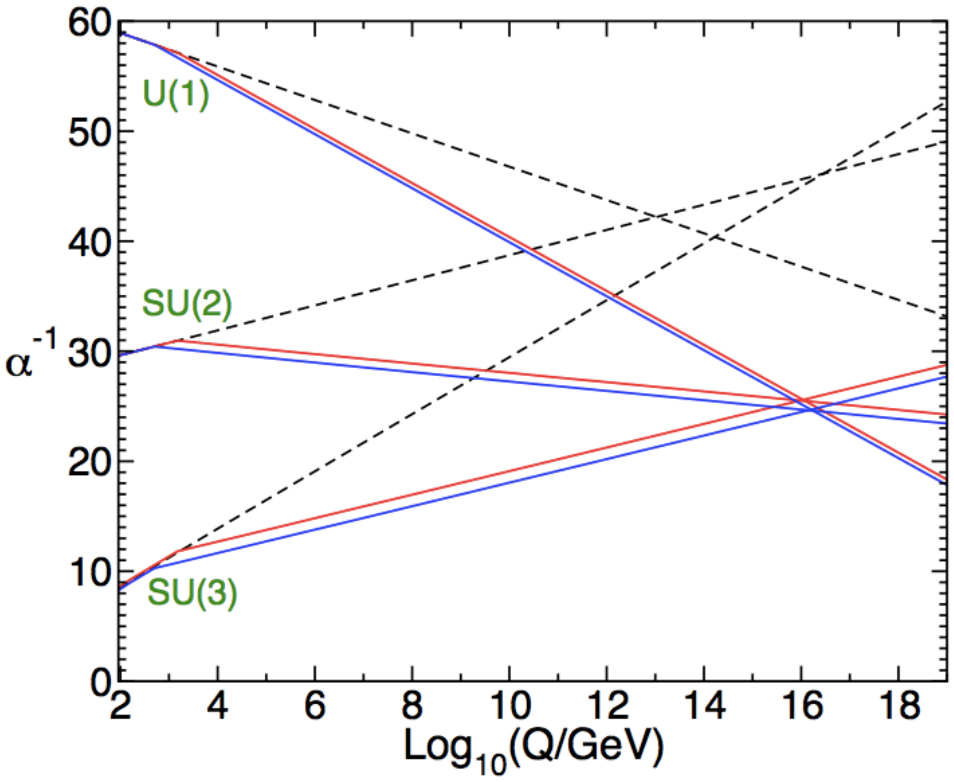
Splitting Mass Spectra in Higgs-Anomaly Mediation

Norimi Yokozaki (Tohoku U.)

Wen Yin, Norimi Yokozaki, arXiv:1607.05705 (PLB)

See also
Tsutomu T. Yanagida, Wen Yin, Norimi Yokozaki, arXiv:1608.06618 (JHEP)

Why SUSY



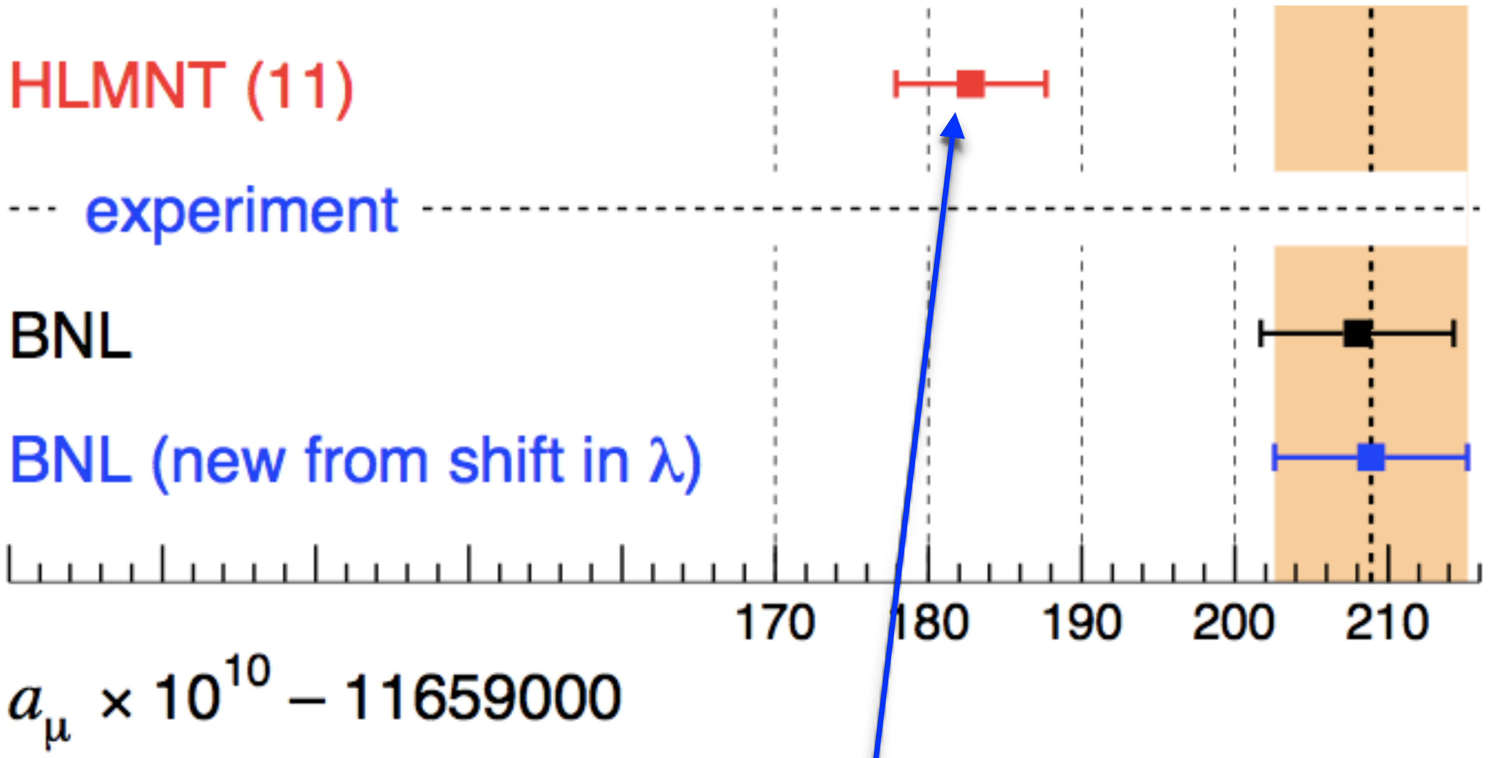
[from SUSY primer, S. Martin]

- Gauge coupling unification
  → Indicating grand unification
  → Matter unification
  → Charge quantization

- Absence of the quadratic divergences in the scalar potential (SM Higgs, PQ-breaking scalar, inflaton)

- There is another experimental motivation

Muon g-2 anomaly



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

SM value

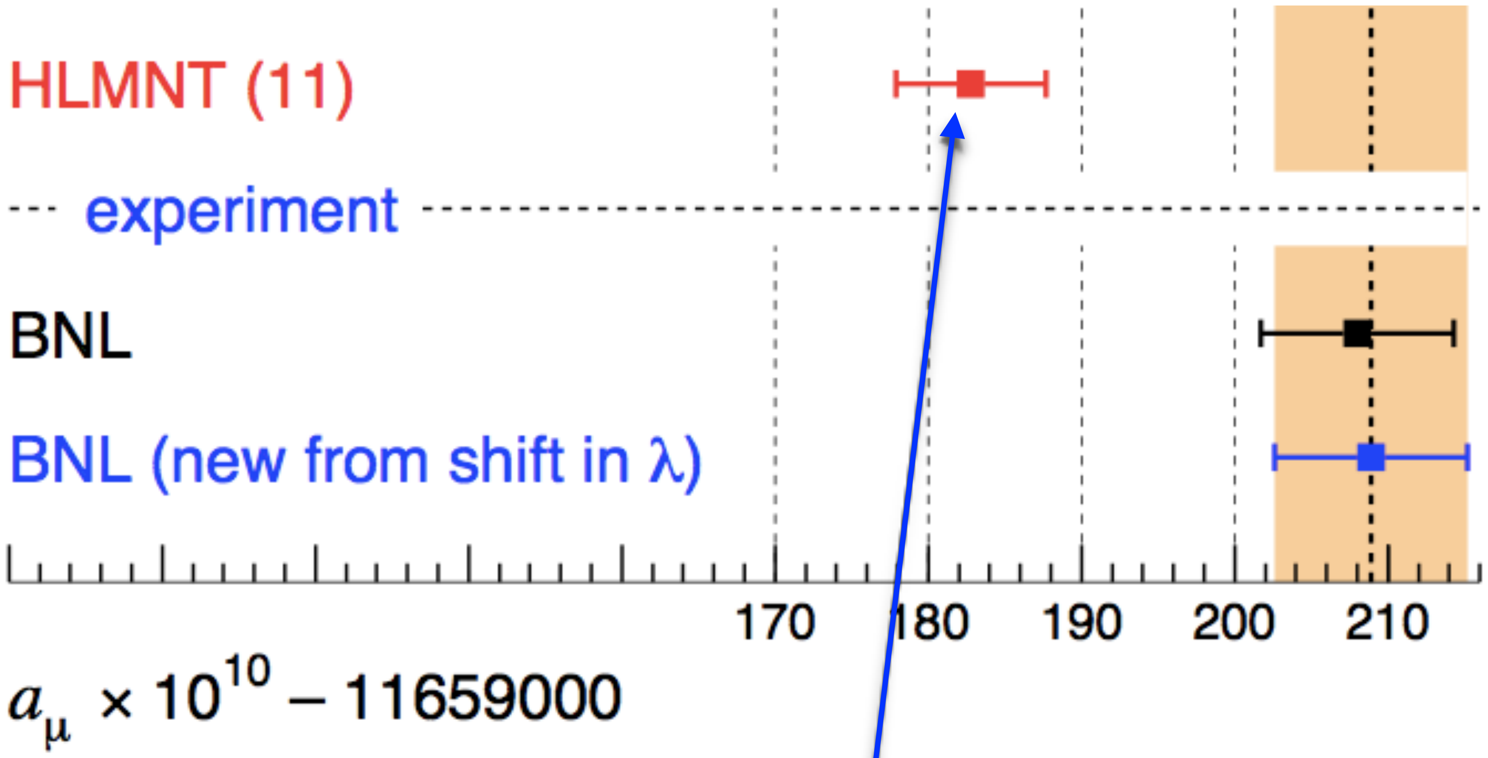
>3σ deviation from SM prediction!

[Also, Davier et al., 2016 → 3.6σ]

$$\mathcal{L} = \frac{e}{4m_\mu}(a_\mu)^{\rm NP}\bar{\mu}\sigma_{\alpha\beta}\mu F^{\alpha\beta}$$

$(a_\mu)^{\rm NP} \approx 2 \times 10^{-9}$ is required

Muon g-2 anomaly



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

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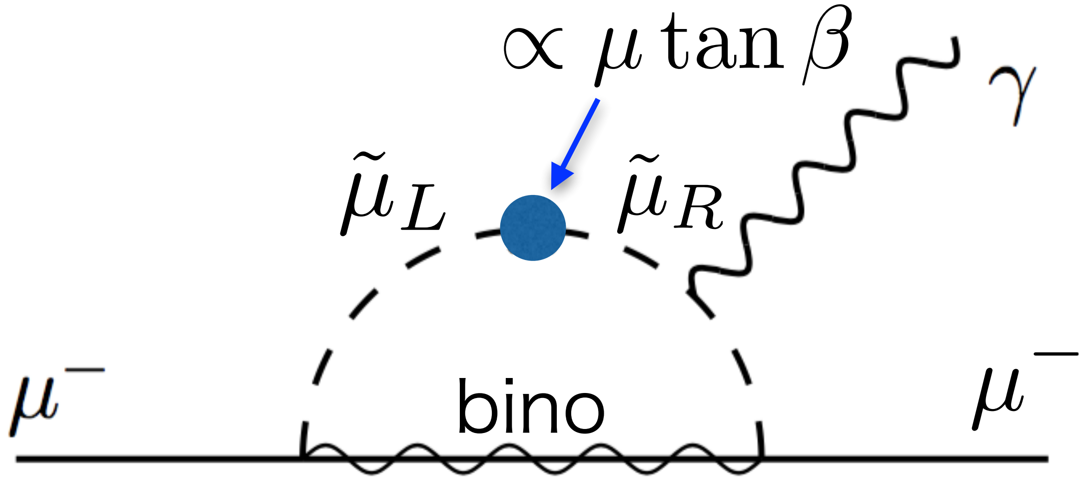
SM value

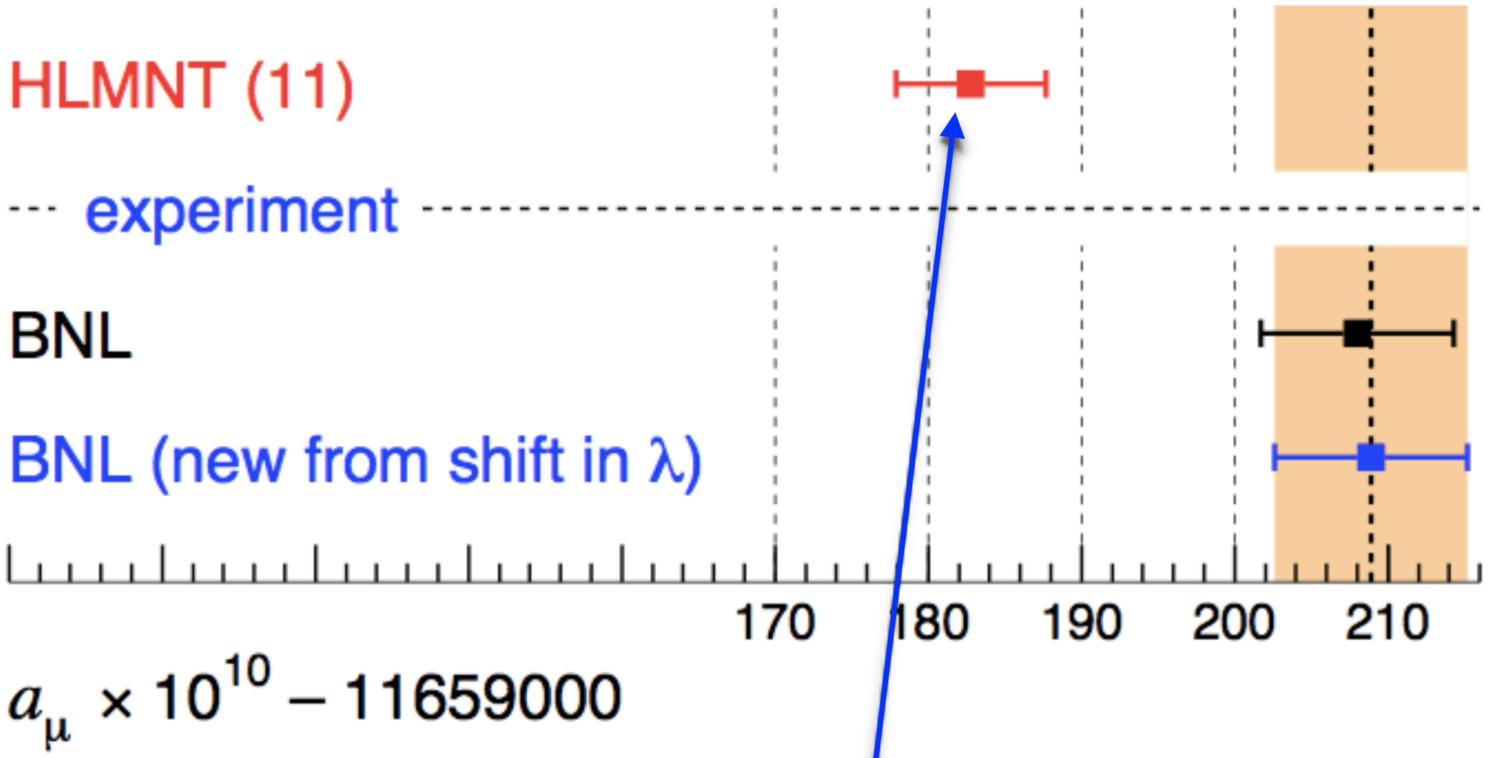
$\propto \mu \tan\beta$



Relevant SUSY particles should be light as O(100) GeV

[Lopez, Nanopoulos and Wang, 1994; Chattopadhyay and Nath, 1996; Moroi, 1996]

Muon g-2 anomaly



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

SM value

>3σ deviation from SM prediction!

[Also, Davier et al., 2016 → 3.6σ]

However, it is not easy to explain the muon g-2 in MSSM, in a way consistent with GUT.

Difficulties

- LHC SUSY search
  → heavy squarks and gluino of >1.4 -1.8 TeV

- Higgs boson mass of 125 GeV → heavy stops of ~10 TeV

- Muon g-2
  → light sleptons and neutralino/chargino of ~100-500 GeV

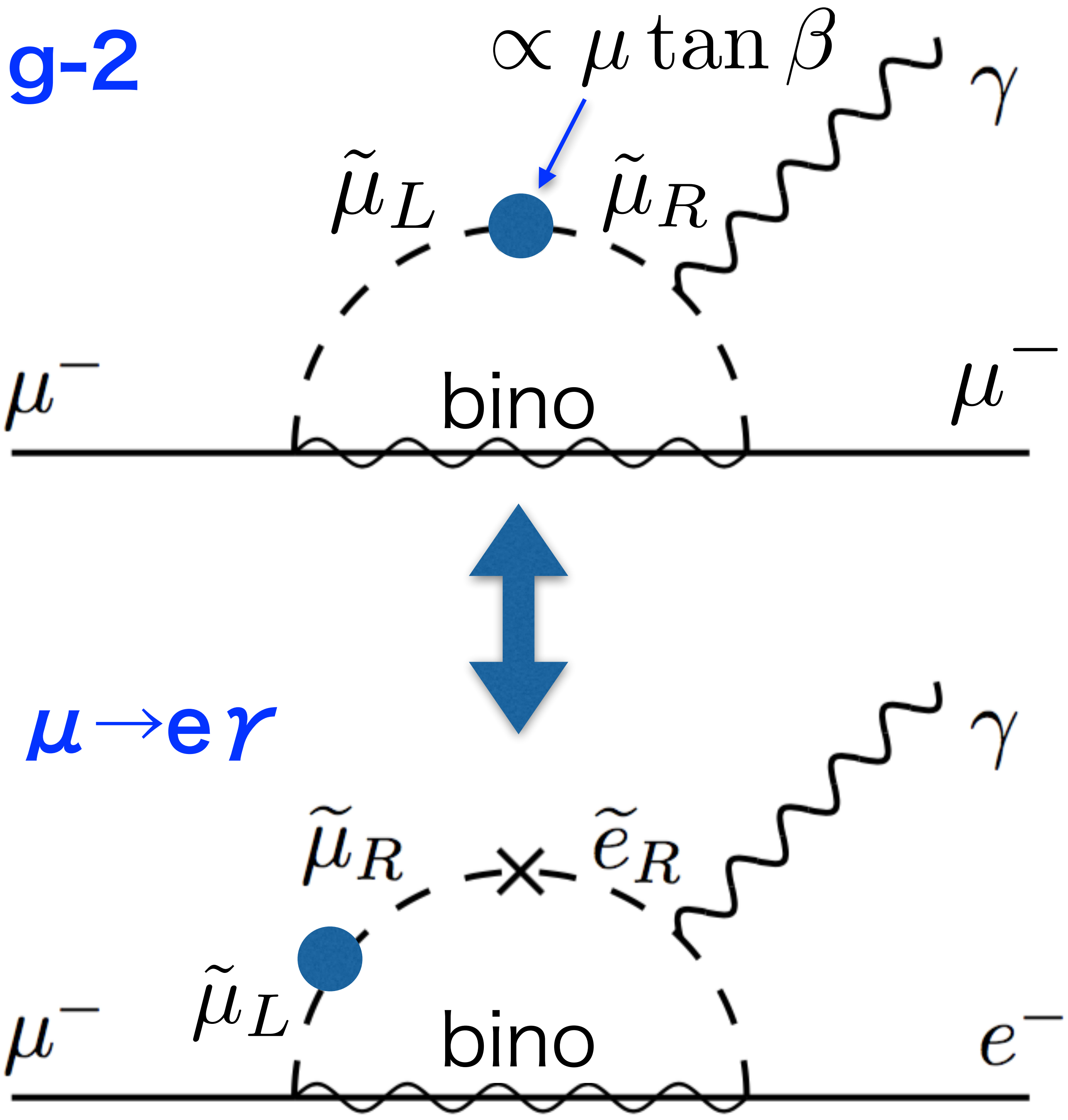
- Grand Unification → Slepton and squarks live in same GUT multiplet, **10=(Q, U*, E*) 5*=(L, D*)**
  It is natural that their masses are degenerated at the tree level. GUT breaking effects may be required.

- Naively, gaugino masses also unify:
  $g_1=g_2=g_3=g_5$ → $M_1=M_2=M_3=M_5$

Flavor problem

g-2

$\mu \to e\gamma$



In general, if muon g-2 enhanced
→ LFV is also enhanced

Higgs-Anomaly mediation

- We considered a simple model explaining the muon g-2, without difficulties concerning the GUT embedding and flavor violation (Yin-Yokozaki, 2016)

In our model, sfermion and gaugino masses originate from anomaly mediation and Higgs loop effects; therefore, no SUSY flavor problem arises

Refs for Anomaly mediation:
[Giudice, Luty, Murayama, Rattazzi; Randall, Sundrum, 1999]

Higgs-Anomaly mediation

- We considered a simple model explaining the muon g-2, without difficulties concerning the GUT embedding and flavor violation (Yin-Yokozaki, 2016)

Recipe:

- 1, Sequestering the matter fields and SUSY breaking field
  → squarks and sleptons are massless at the tree level
  (gauginos are also massless)

Solving the flavor problem

- 2, Making the gravitino heavy (~100 TeV)
  → Anomaly mediation becomes effective, inducing GUT breaking effects

Relaxing the gravitino problem

- 3, Coupling only Higgs fields and SUSY breaking field directly. **(Note: Higgs soft masses are tachyonic)**

Our setup

$$K = -3M_P^2 \ln\left[1 - \frac{f(Z,Z^\dagger) + \phi_i^\dagger\phi_i + \Delta K}{3M_P^2}\right],$$

SUSY breaking field

(quark, lepton, Higgs)

$$\Delta K = \underset{>0}{c_Z}\frac{|Z|^2}{M_P^2}(|H_u|^2 + |H_d|^2),$$

Our setup

$$K = -3M_P^2 \ln\left[1 - \frac{f(Z, Z^\dagger) + \phi_i^\dagger \phi_i}{3M_P^2}\right],$$

SUSY breaking field

(quark, lepton, Higgs)

First, we start with a sequestered form

Sfermion masses vanish at the tree-level

Simple and important assumption to solve SUSY flavor problem

(gaugino masses also vanish at the tree-level)

Ref. for sequestered form [Randall, Sundrum, 1999]

Our setup

$$K = -3M_P^2 \ln\left[1 - \frac{f(Z, Z^\dagger) + \phi_i^\dagger \phi_i}{3M_P^2}\right],$$

SUSY breaking field

(quark, lepton, Higgs)

$$\boxed{M_1 \simeq \frac{33}{5}\frac{g_1^2}{16\pi^2} m_{3/2}\,, \quad M_2 \simeq \frac{g_2^2}{16\pi^2} m_{3/2}, \quad M_3 \simeq -3\frac{g_3^2}{16\pi^2} m_{3/2},}$$

(gaugino masses also vanish at the tree-level)

Ref. for sequestered form [Randall, Sundrum, 1999]

Our setup

$$K = -3M_P^2 \ln\left[1 - \frac{f(Z,Z^\dagger) + \phi_i^\dagger \phi_i}{3M_P^2}\right],$$

SUSY breaking field

(quark, lepton, Higgs)

Sfermion masses vanish at the tree-level

From anomaly mediation effects, sfermion get masses at the two-loop level. However, slepton mass becomse tachyonic

$$m_{\bar{E}}^2 \approx -22 g_Y^4 \frac{m_{3/2}^2}{16\pi^2}$$

(Left-handed slepton has also tachyonic mass)

Our setup

$$K = -3M_P^2 \ln\left[1 - \frac{f(Z, Z^\dagger) + \phi_i^\dagger \phi_i}{3M_P^2}\right],$$

SUSY breaking field　　　(quark, lepton, Higgs)

Sfermion masses vanish at the tree-level

From anomaly mediation effects, sfermion get masses at the two-loop level. However, slepton mass becomse tachyonic

Tachyonic slepton problem in anomaly mediation

→ From another perspective, slepton can be light which is favored for the muon g-2

GUT breaking effects are naturally included

Our setup

$$K = -3M_P^2 \ln \left[1 - \frac{f(Z, Z^\dagger) + \phi_i^\dagger \phi_i + \Delta K}{3M_P^2} \right],$$

SUSY breaking field

(quark, lepton, Higgs)

$$\Delta K = \underset{>0}{c_Z} \frac{|Z|^2}{M_P^2} (|H_u|^2 + |H_d|^2),$$

Only Higgs doublets couple to the SUSY breaking field directly

(Solving tachyonic slepton problem and making third generation sfermion heavy)

Our setup

$$K = -3M_P^2 \ln \left[1 - \frac{f(Z, Z^\dagger) + \phi_i^\dagger \phi_i + \Delta K}{3M_P^2} \right],$$

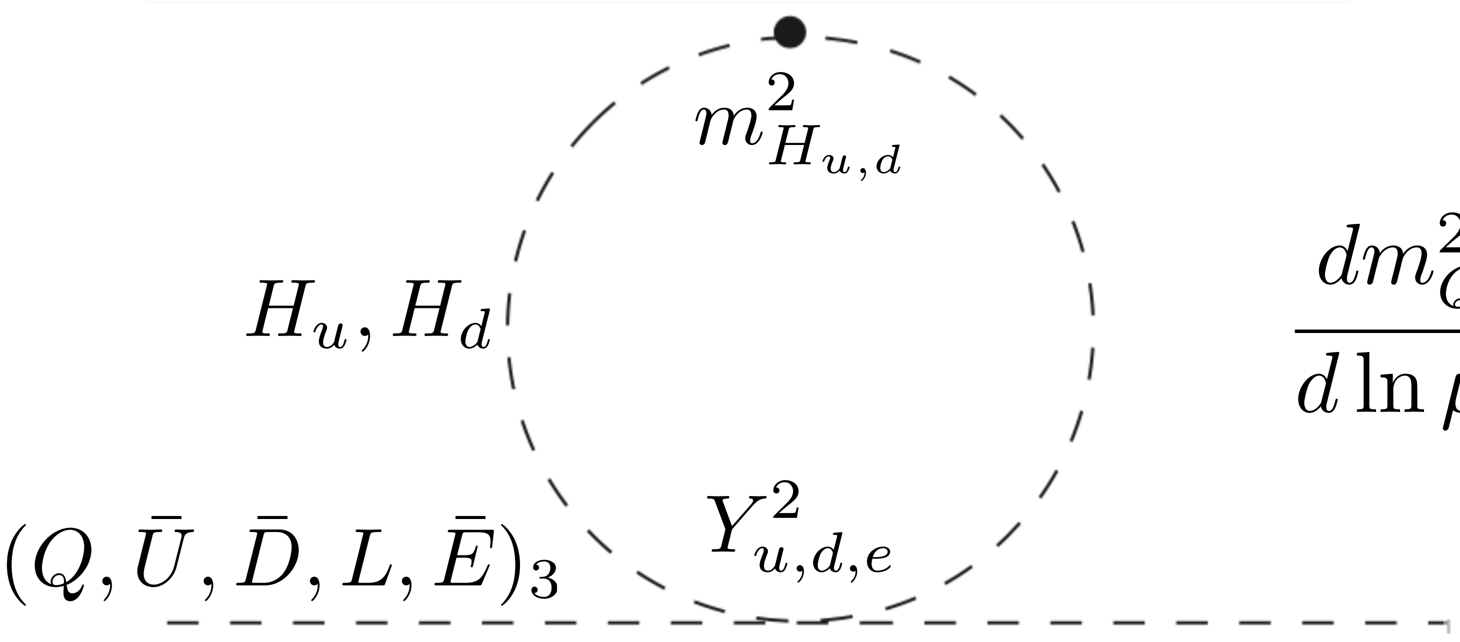
SUSY breaking field

(quark, lepton, Higgs)

$$\Delta K = \underset{>0}{c_Z} \frac{|Z|^2}{M_P^2} (|H_u|^2 + |H_d|^2),$$

Only Higgs doublets couple to the SUSY breaking field directly

Negative Higgs soft mass squares are important!

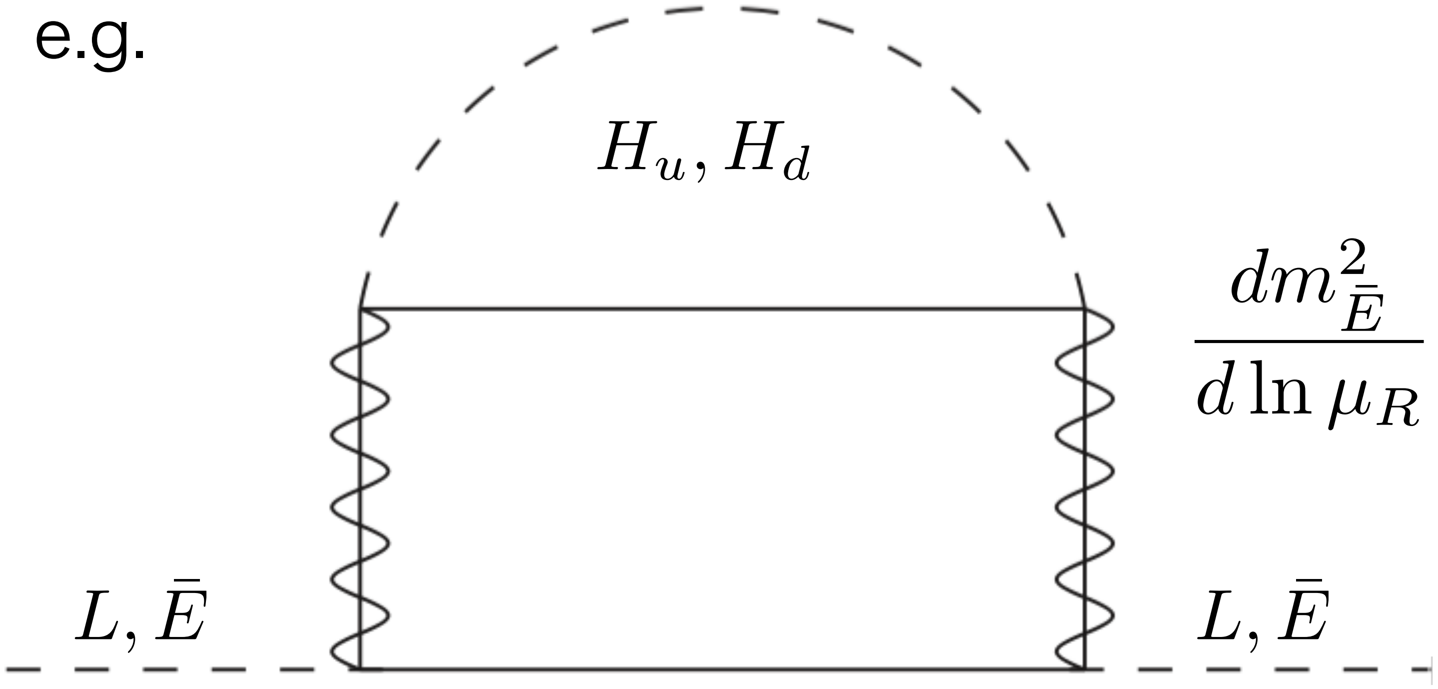


$$\frac{dm^2_{Q_3}}{d\ln\mu_R} \ni \frac{1}{8\pi^2}(Y_t^2 m^2_{H_u} + Y_b^2 m^2_{H_d})$$

<0

Lifting up 3rd generation sfermion masses at one-loop level
Important for the Higgs mass of 125 GeV

e.g.

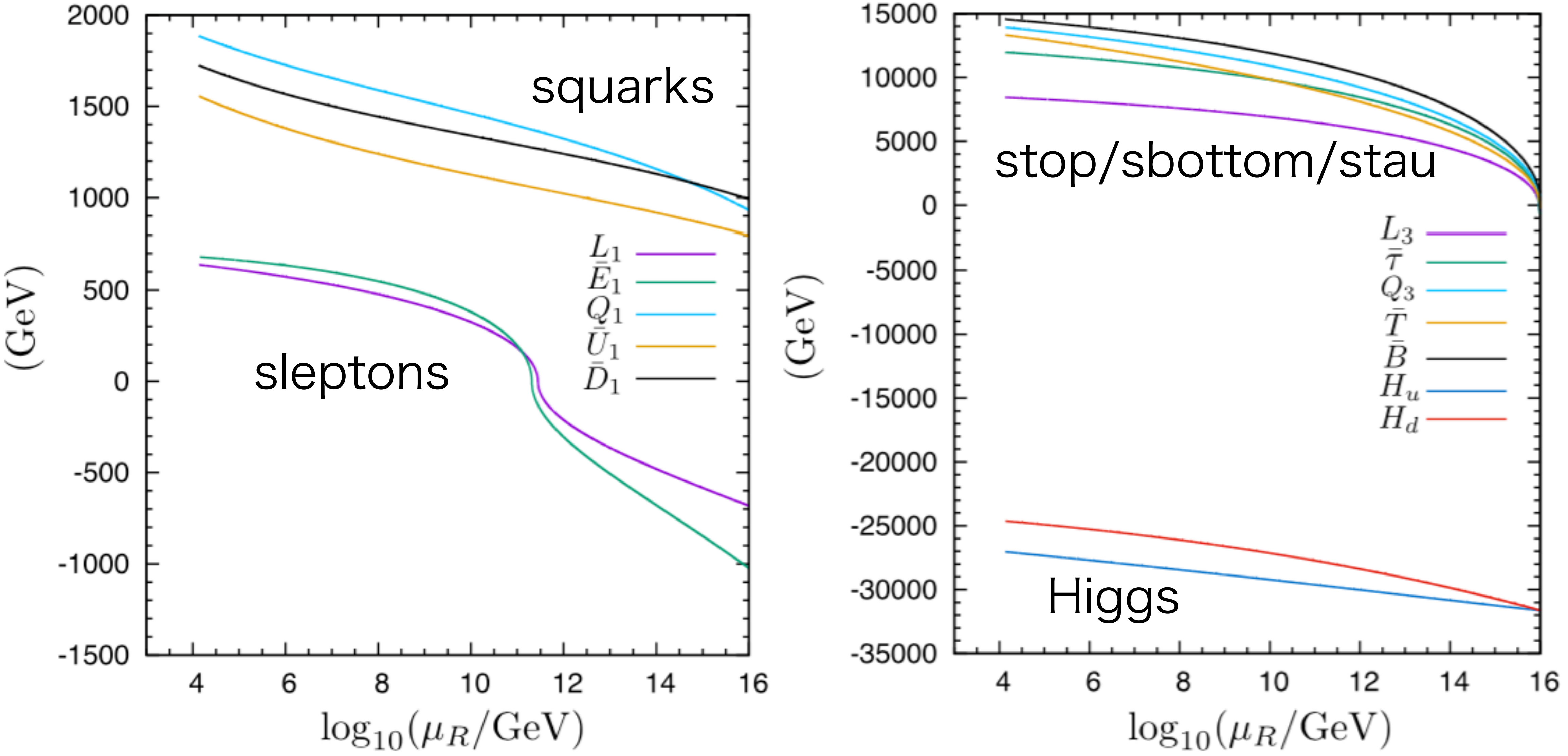


$$\frac{dm^2_{\bar{E}}}{d\ln\mu_R} \ni \frac{1}{(16\pi^2)^2}\left[\frac{36}{25}g_1^4(m^2_{H_u} + m^2_{H_d})\right]$$

<0

Lifting up slepton masses, avoiding the tachyonic slepton problem at two-loop level

RGE runnings of soft mass parameters

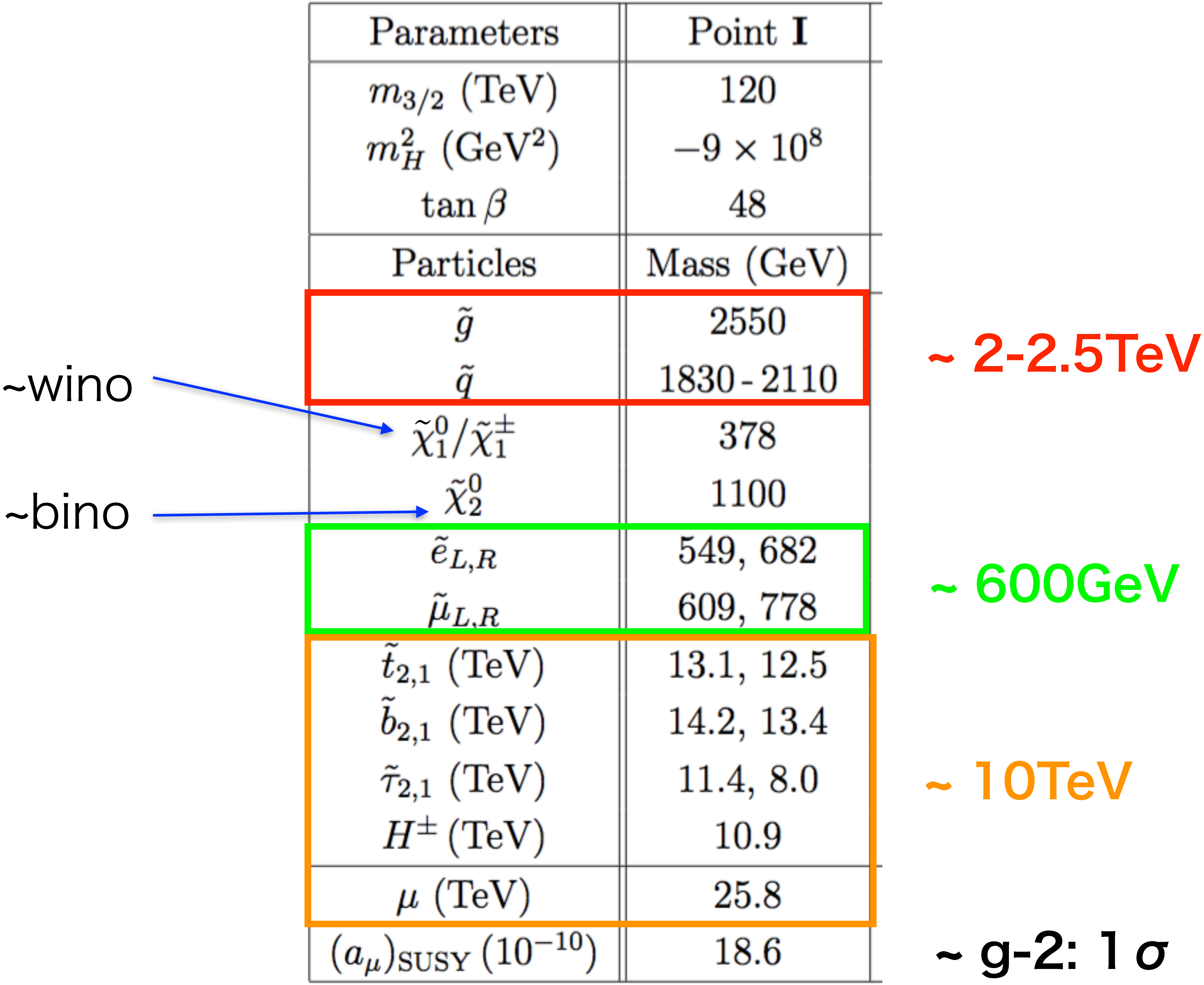


$$m_{3/2} = 120\,\mathrm{TeV},\ \tan\beta = 48,\ \text{and}\ m_H = -10^9\,\mathrm{GeV}^2.$$

(Still D-flat direction of the Higgs potential is safe!)

Mass spectrum and muon g-2

(Including leading two-loop corrections)



Parameters	Point **I**
$m_{3/2}$ (TeV)	120
m_H^2 (GeV^2)	-9×10^8
$\tan\beta$	48
Particles	Mass (GeV)
$\tilde{g}$	2550
$\tilde{q}$	1830 - 2110
$\tilde{\chi}_1^0/\tilde{\chi}_1^\pm$	378
$\tilde{\chi}_2^0$	1100
$\tilde{e}_{L,R}$	549, 682
$\tilde{\mu}_{L,R}$	609, 778
$\tilde{t}_{2,1}$ (TeV)	13.1, 12.5
$\tilde{b}_{2,1}$ (TeV)	14.2, 13.4
$\tilde{\tau}_{2,1}$ (TeV)	11.4, 8.0
$H^\pm$ (TeV)	10.9
μ (TeV)	25.8
$(a_\mu)_{\rm SUSY}$ (10^{-10})	18.6

~wino

~bino

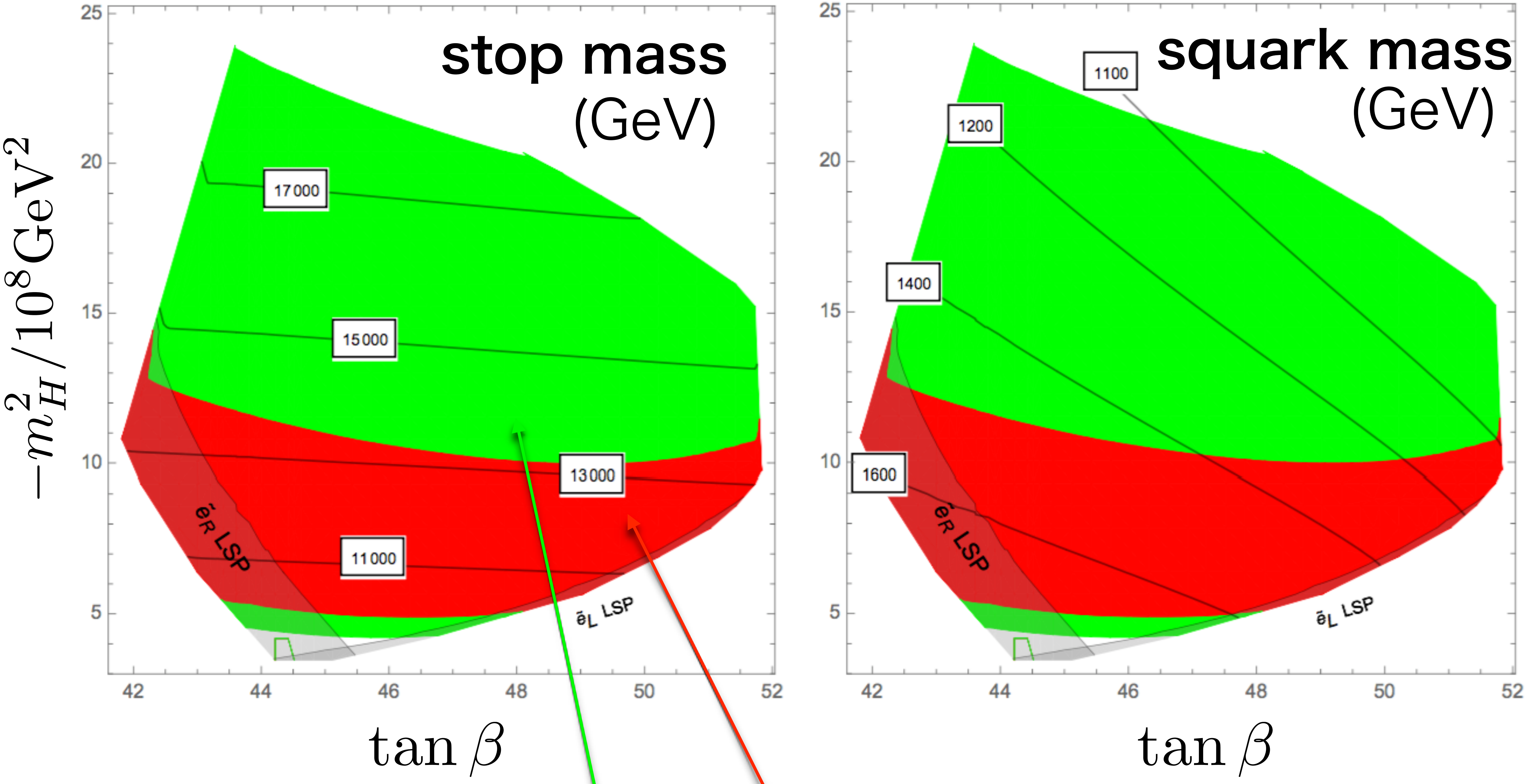
~ 2-2.5TeV

~ 600GeV

~ 10TeV

~ g-2: 1σ

$m_{3/2}$=100 TeV



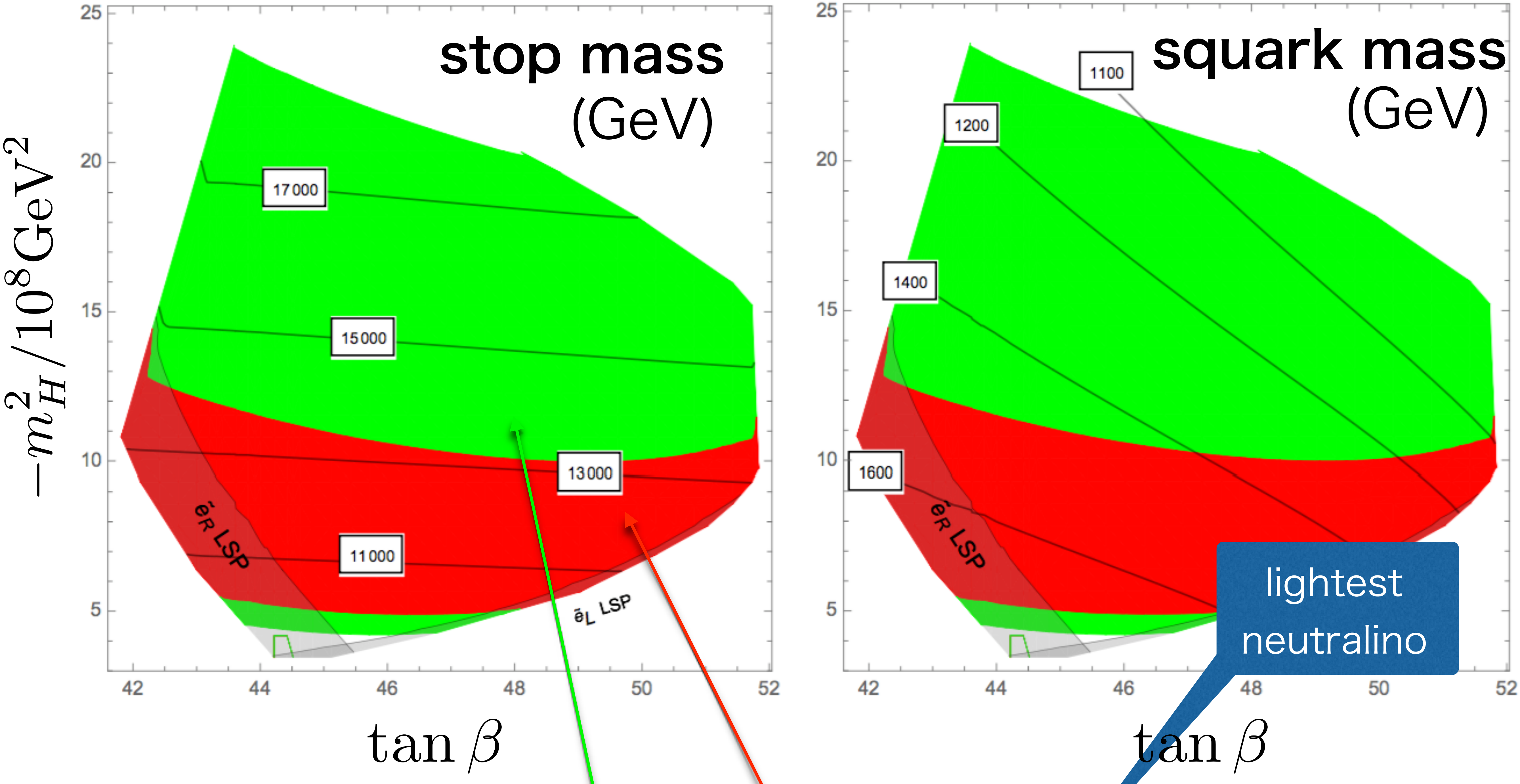
2σ

g-2: 1σ

gluino mass: 2.2 TeV

wino mass: 320 GeV

$m_{3/2}$=100 TeV



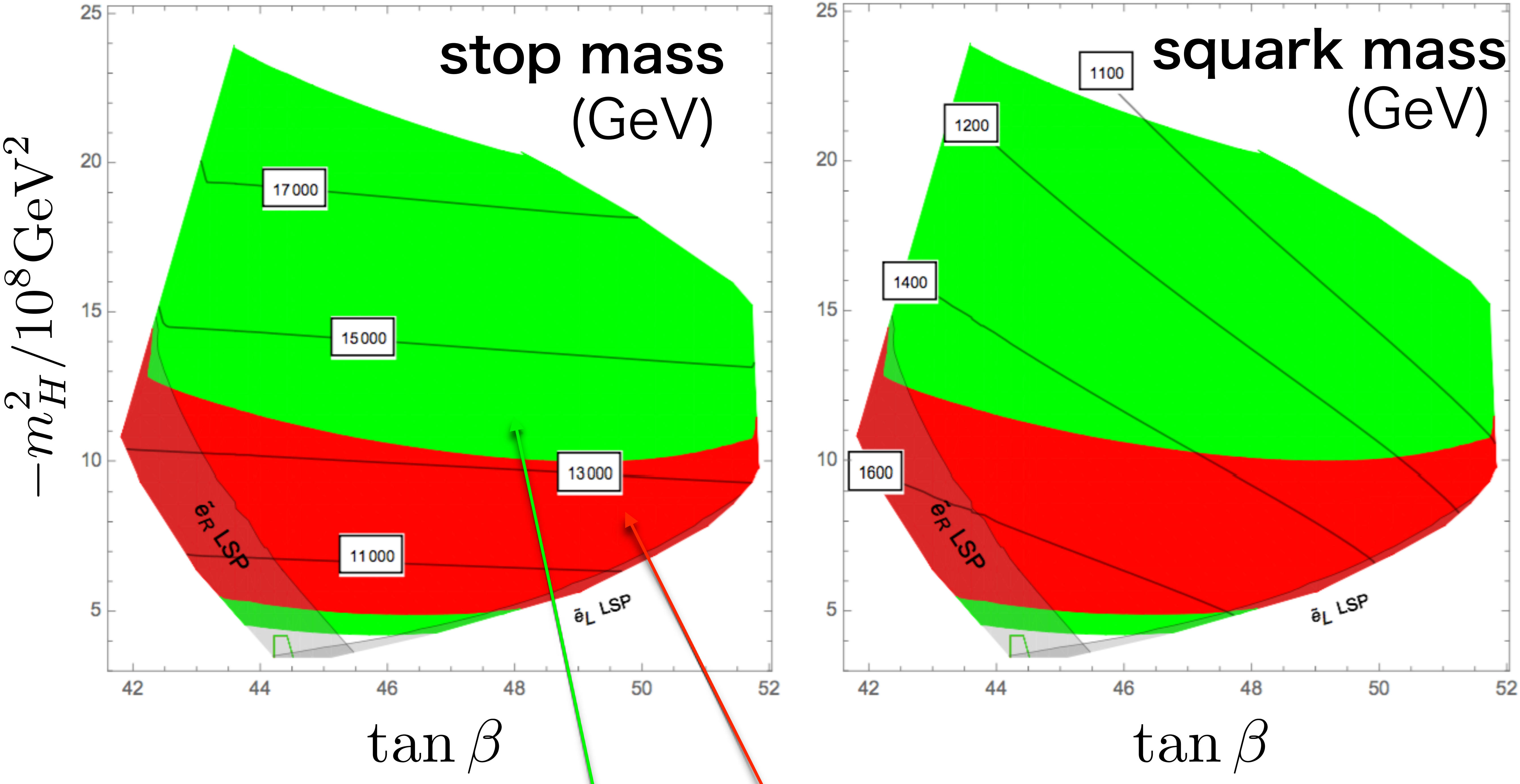
2σ

g-2: 1σ

gluino mass: 2.2 TeV

wino mass: 320 GeV

$m_{3/2}$=100 TeV



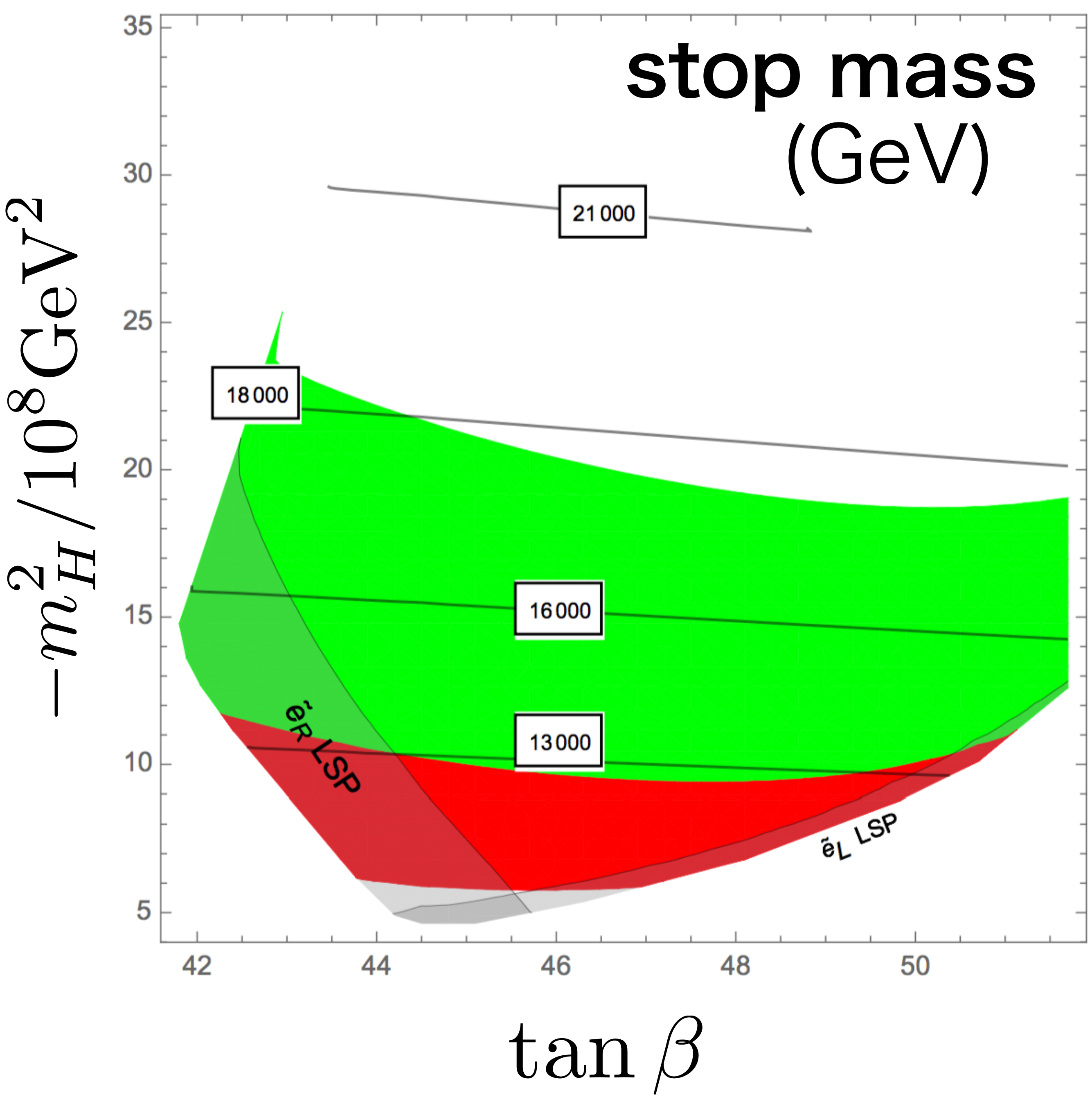
2σ

g-2: 1σ

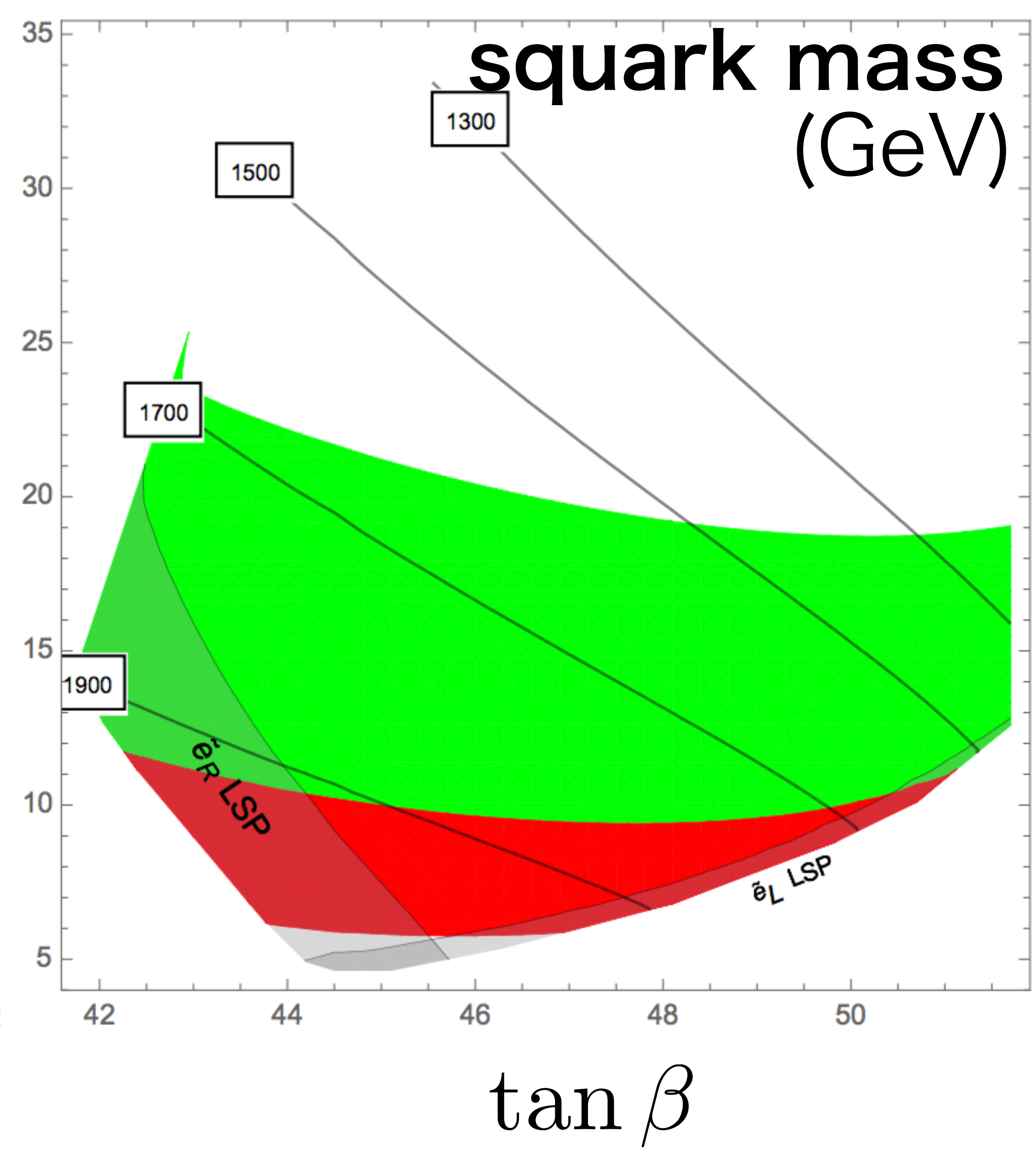
gluino mass: 2.2 TeV

wino mass: 320 GeV

$m_{3/2}$=120 TeV



stop mass (GeV)

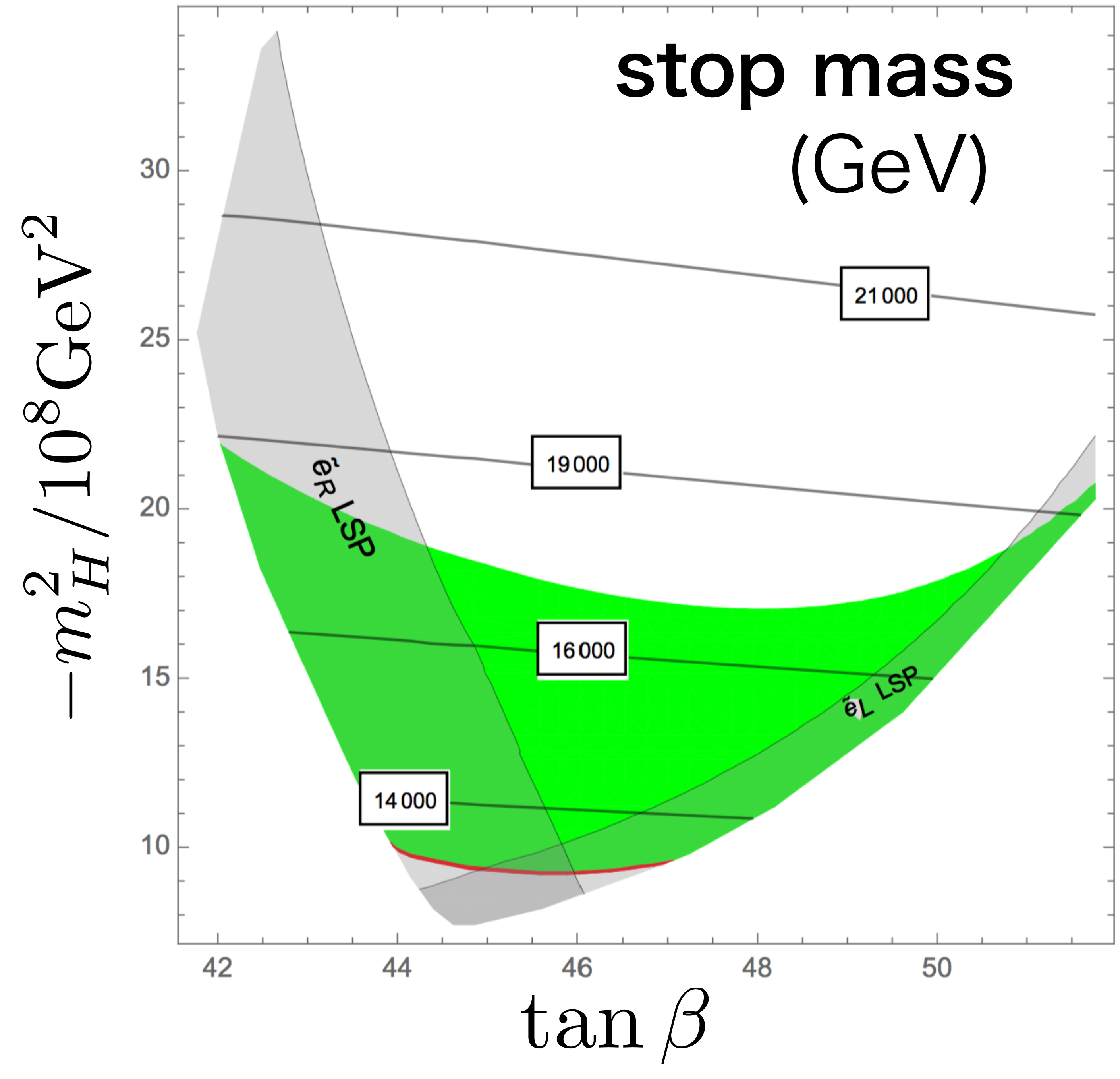


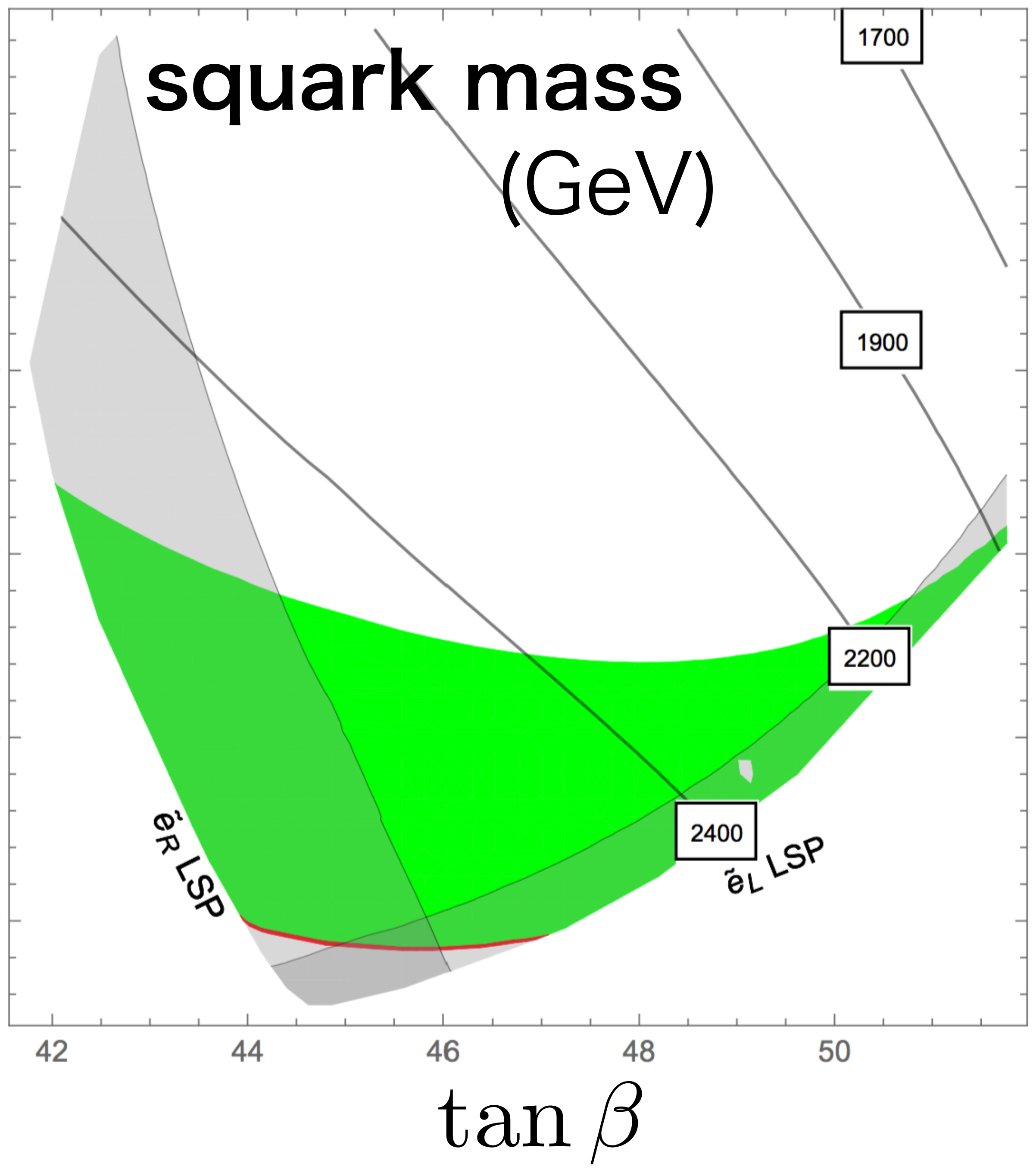
squark mass (GeV)

gluino mass: 2.5 TeV

wino mass: 380 GeV

$m_{3/2}$=160 TeV

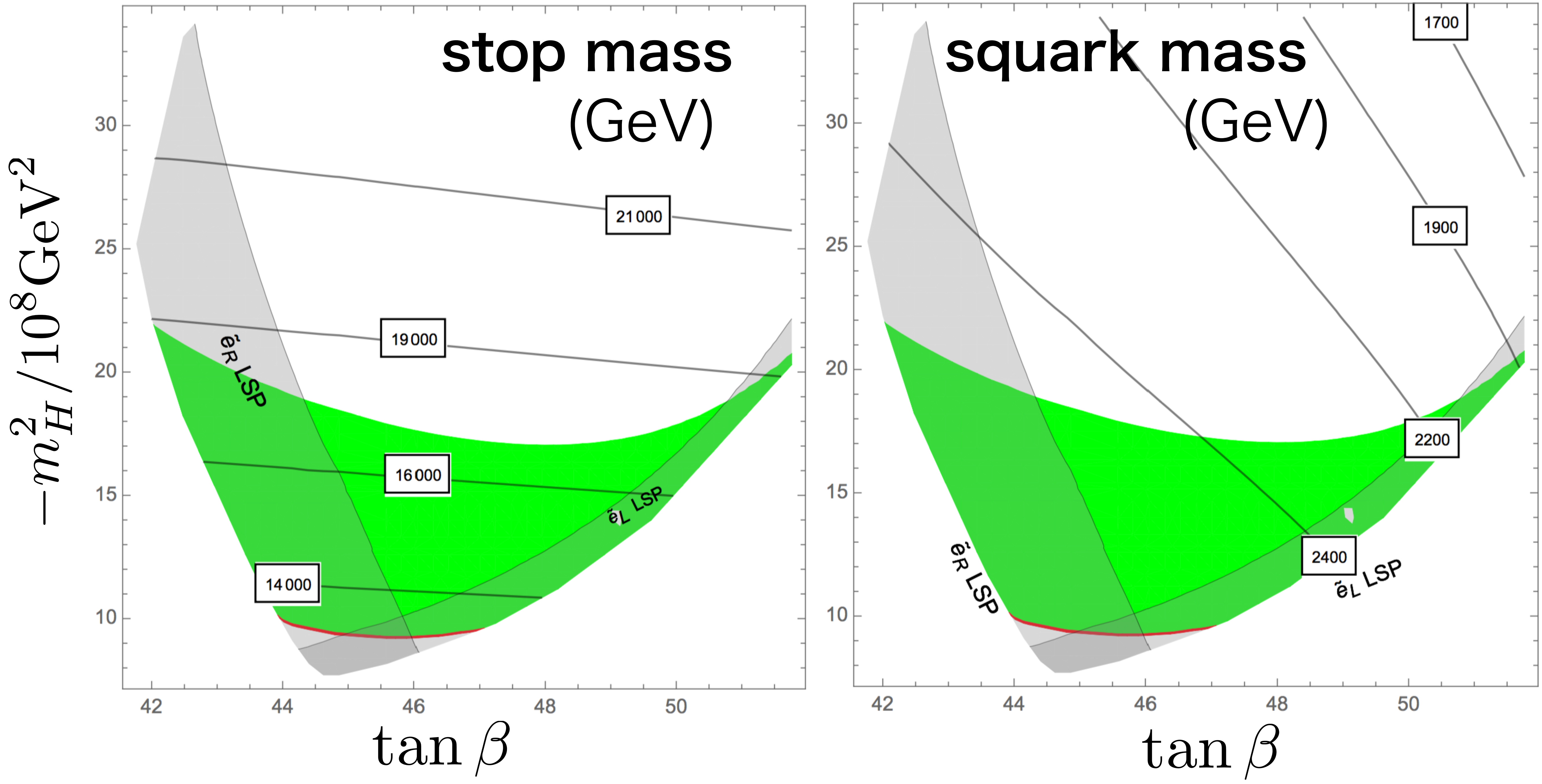




gluino mass: 3.3 TeV

wino mass: 500 GeV

$m_{3/2}$=160 TeV

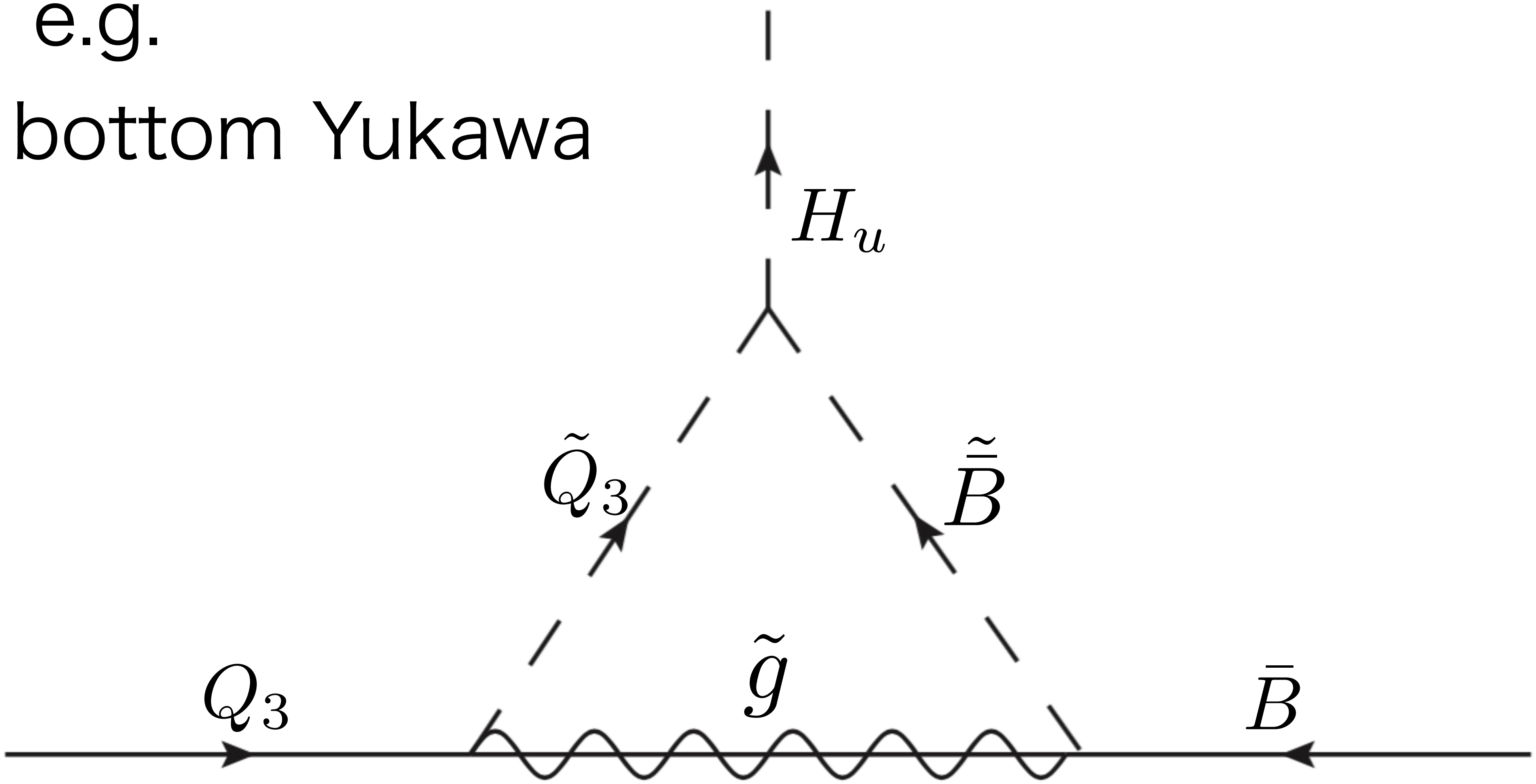


Wino search at the LHC can cover the region consistent with the muon g-2 (1σ)

Yukawa coupling unification

e.g.

bottom Yukawa

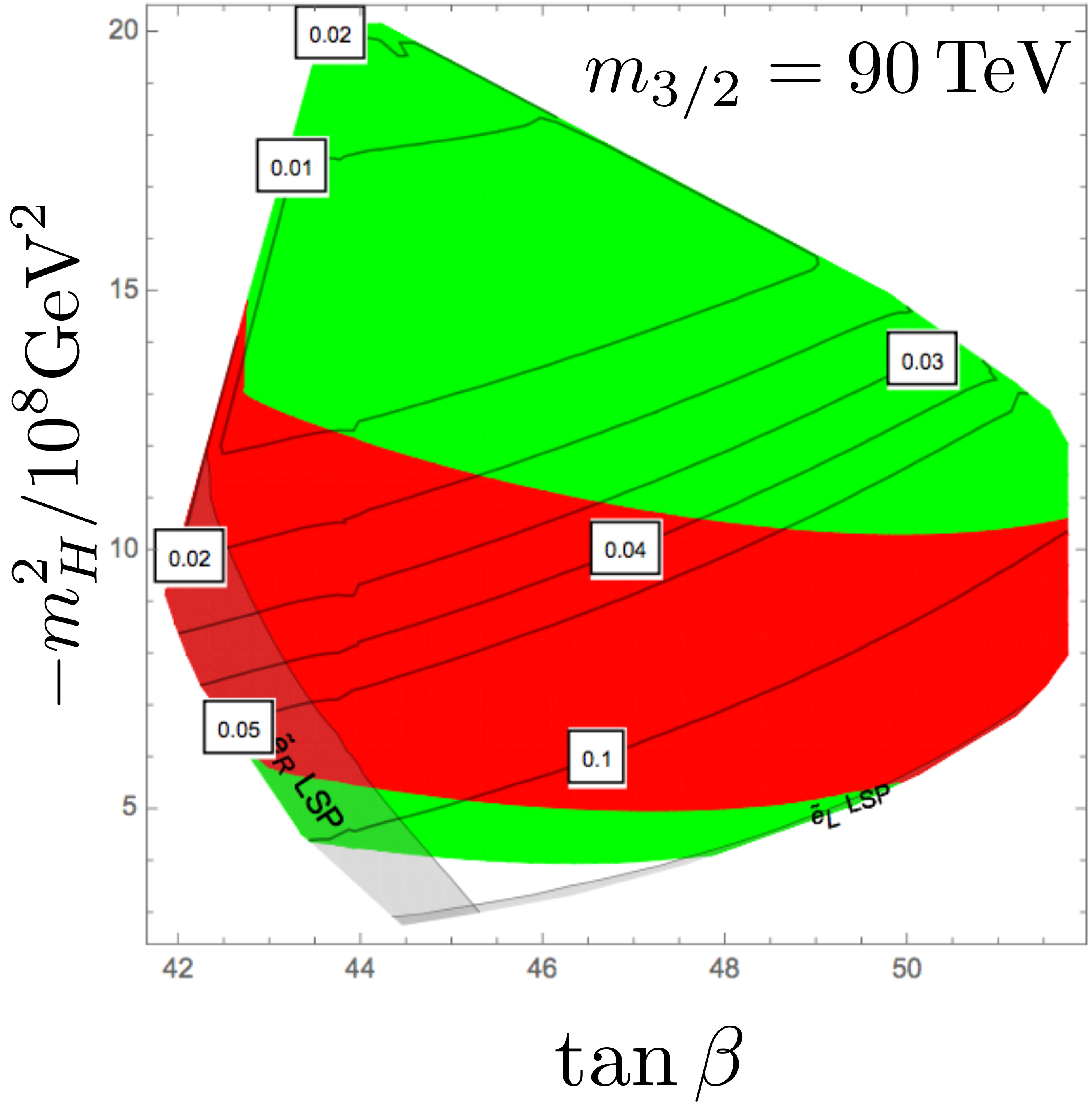


With important threshold corrections

Bottom-Tau unification

Motivated by SU(5)

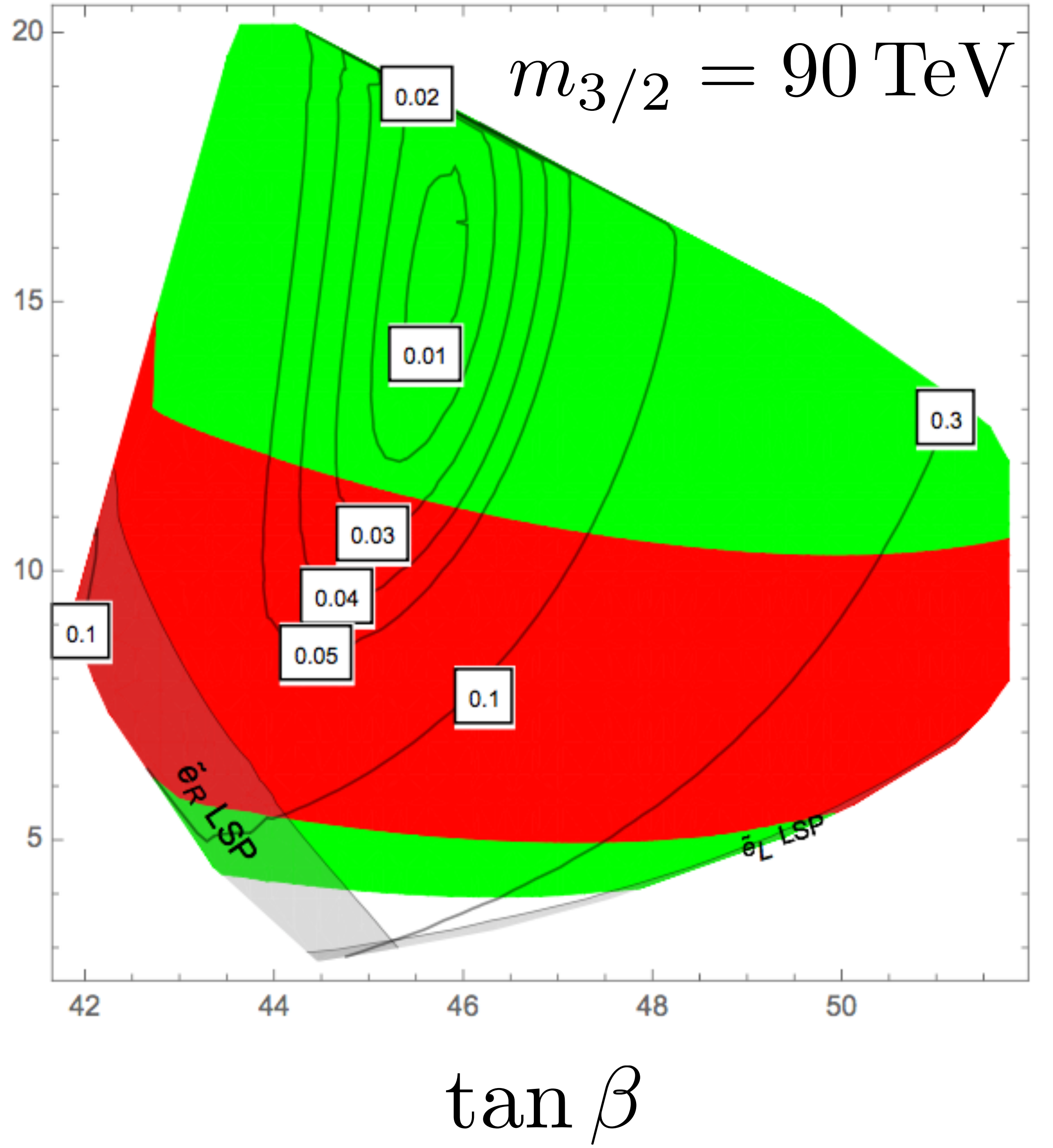
$$\sqrt{(Y_b - Y_\tau)^2}$$



Bottom-Tau-Top unification

Motivated by SO(10)

$$\sqrt{(Y_b - Y_\tau)^2 + (Y_t - Y_\tau)^2 + (Y_t - Y_b)^2}$$



Summary

- We have found a simple model which has many benefits
  - Muon g-2 is explained.
  - The Higgs boson mass of 125 GeV is explained with ~10 TeV stops.
  - No SUSY flavor problem
  - Tachyonic slepton problem is solved
  - Gravitino problem is significantly relaxed with ~100 TeV gravitino

Summary

- Wino, squarks and gluino can be seen at the LHC.
- Yukawa coupling unification is realized.
- No singlet SUSY breaking field is required.
  → Polonyi problem may be relaxed.
- Massless sfermions may be regarded as NG bosons, which may enable us to understand the origin of the family number, three. (Kugo, Yanagida, 1984 ··· Yanagida, Win, Yokozaki, 2016)

- Squarks and sleptons get masses from Higgs soft masses, and their hierarchical masses originate from the structure of the Yukawa couplings

Our scenario

- Quarks and leptons get masses from the VEV of the Higgs field, and their hierarchical masses originate from the structure of the Yukawa couplings.

Standard model

The structure seems natural.