DISCRETE 2018, 11/28

SUSY model for muon g-2 anomaly and dark matter, and its implications

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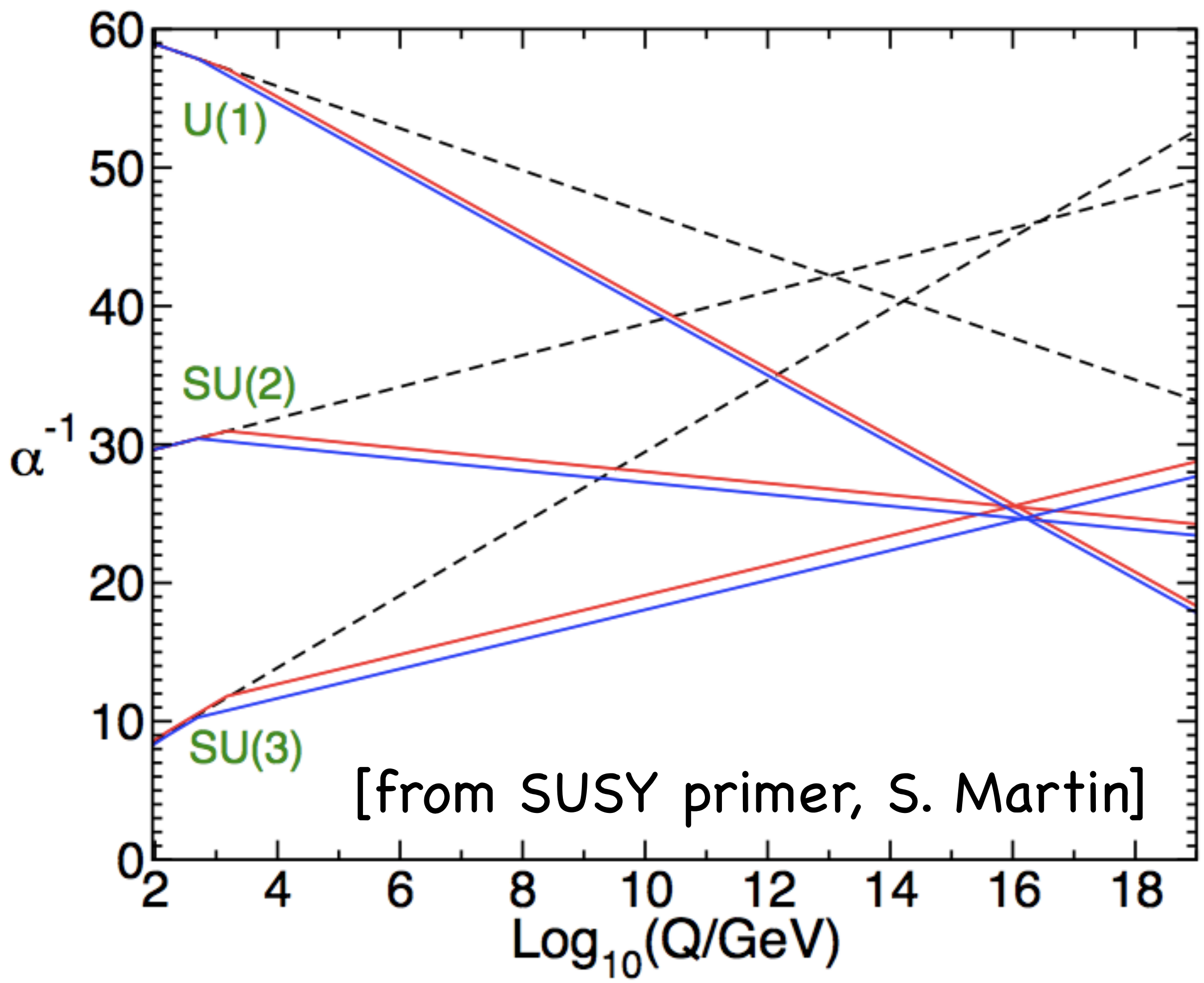
Based on

hopefully

P. Cox, C. Han, T. Yanagida and N.Y. (arXiv:1811.xxxxx)

R. Nagai and N.Y. in preparation

Supersymmetry



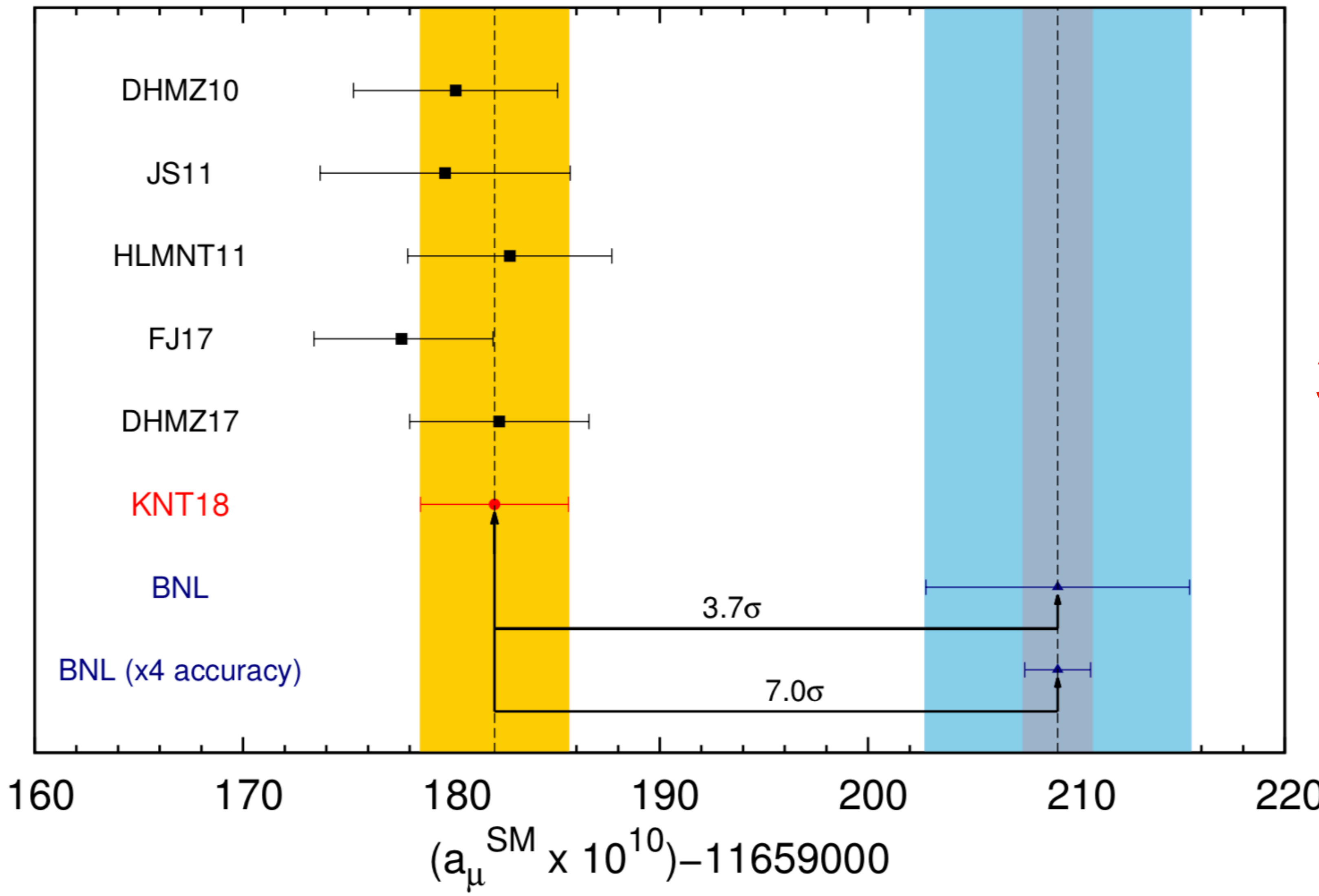
- Gauge coupling unification
  → Grand Unified Theory

- Absence of the quadratic divergence in the scalar potential (Higgs, PQ-breaking scalar, inflaton ⋯)

- Candidates for dark matter (neutralino, gravitino)

- There also exists an experimental motivation

Muon g-2 anomaly



3.7σ deviation

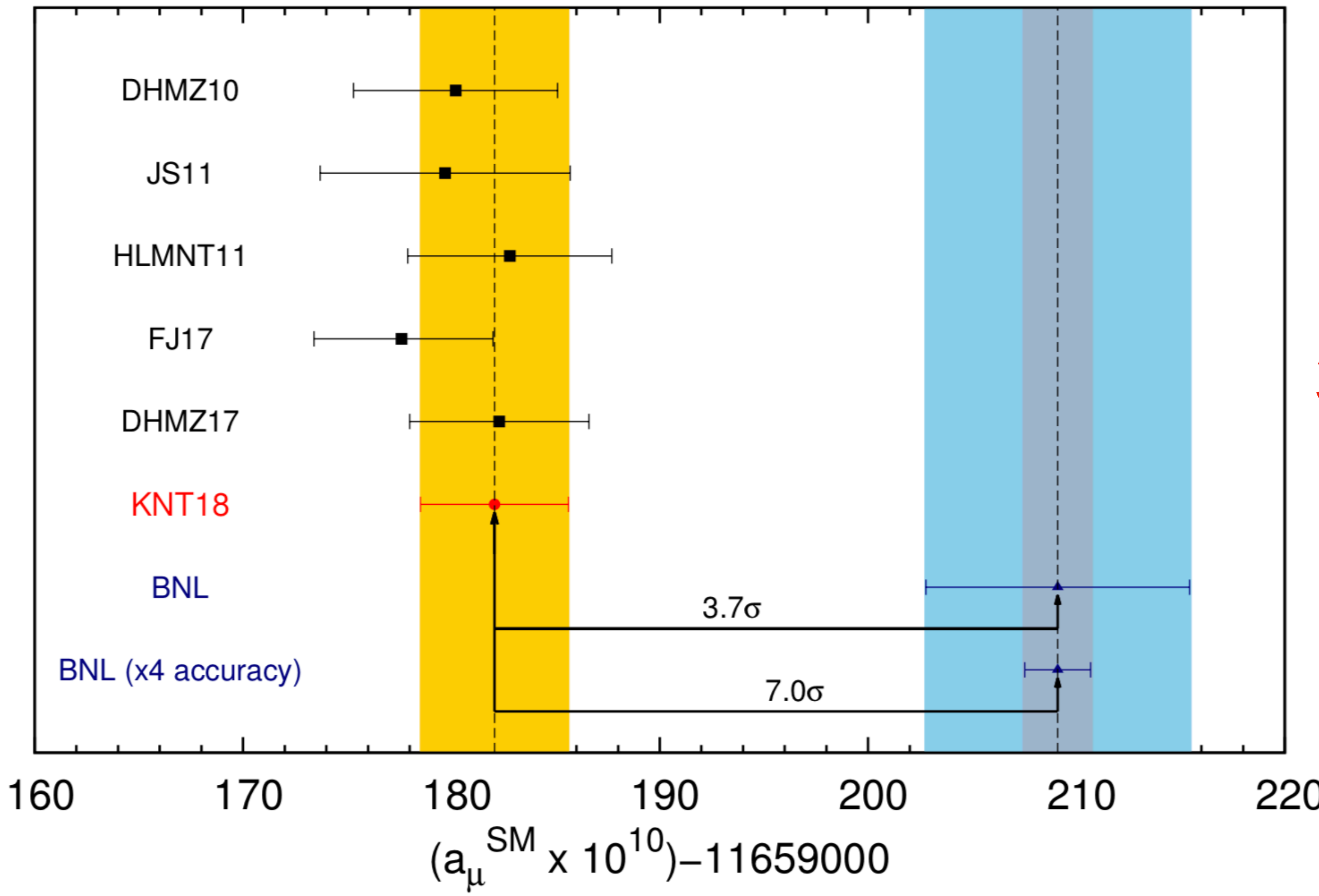
[Keshavarzi, Nomura, Teubner, 2018]

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

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

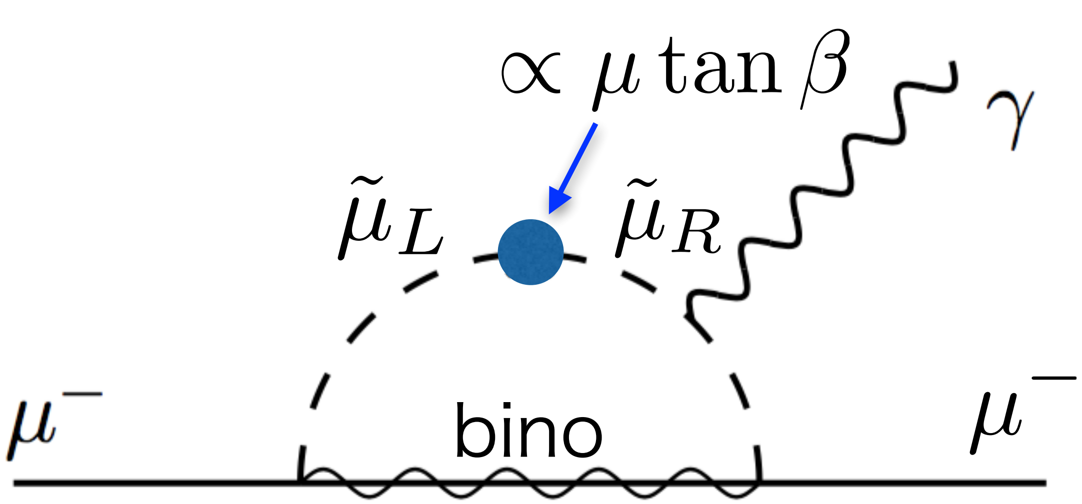
(similar to the size of W-boson contribution)

Muon g-2 anomaly



3.7σ deviation

[Keshavarzi, Nomura, Teubner, 2018]

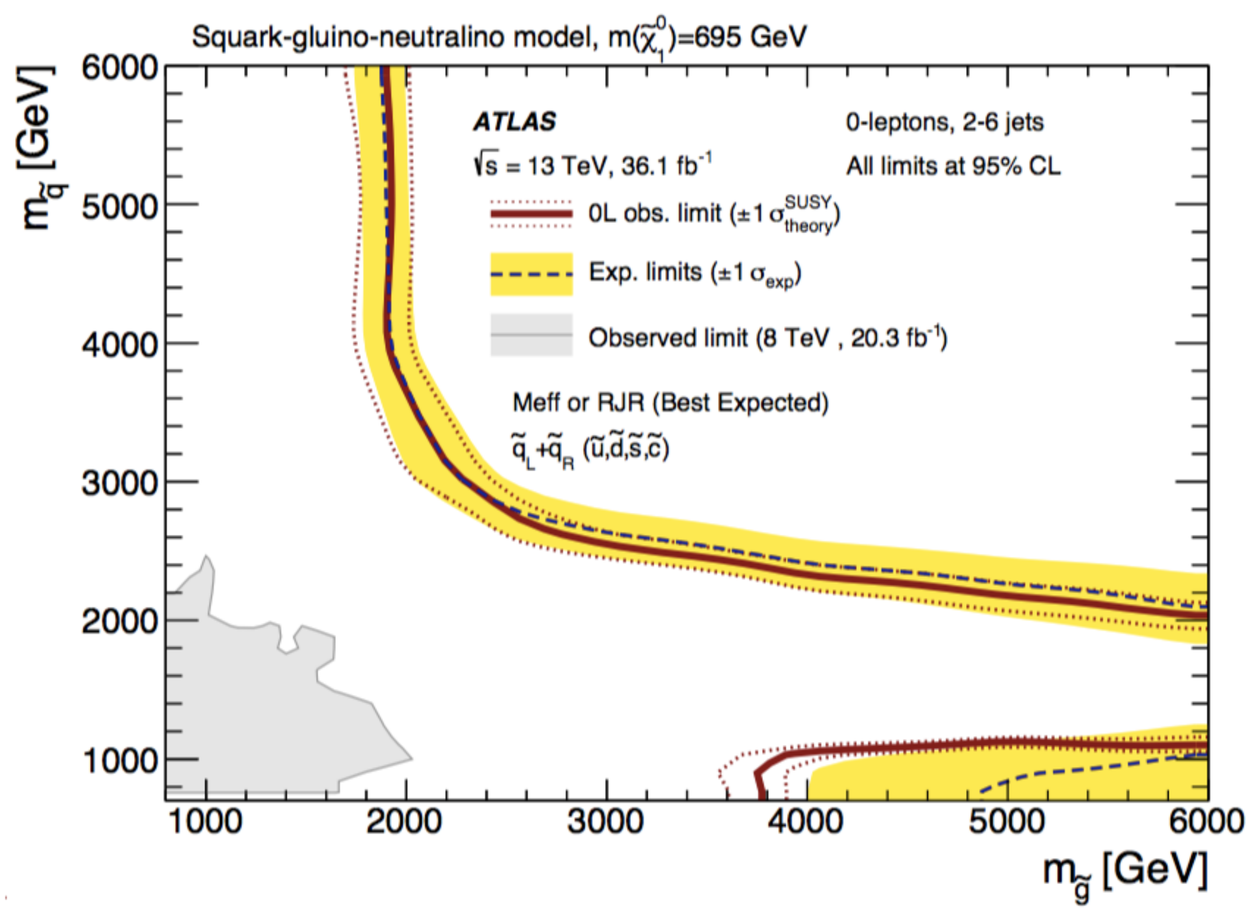


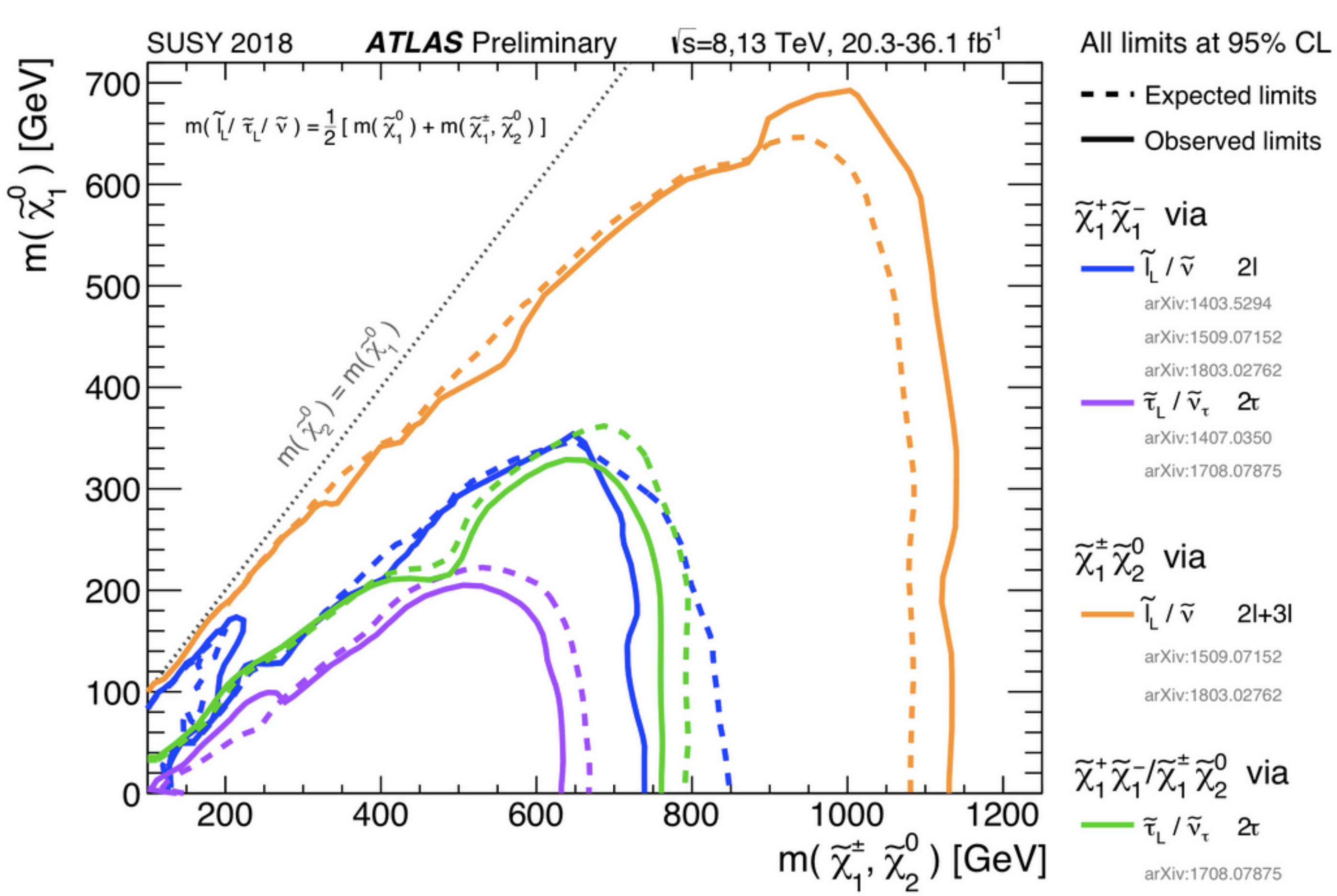
Smuons and neutralino/chargino are required to be O(100)GeV

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

Difficulties

- LHC SUSY searches
  → Squarks and gluino should be heavier than ~2.5 TeV
  → EW sector is also constrained quite severely





Difficulties

- LHC SUSY searches
  → Squarks and gluino should be heavier than ~2.5 TeV
  → EW sector is also constrained quite severely

- Higgs boson mass of 125 GeV
  → Stop masses are ~10 TeV

- No signal in direct detection experiments of dark matter
  → Higgsino is heavy, i.e. μ is large

- Vacuum instability caused by large $\mu \tan\beta$ in the stau-Higgs potential
  → Staus need to be much heavier than smuons

- SUSY flavor problem ($\mu \to e\gamma$, K meson mixing ⋯)

- So we want a simple model which predicts a spectrum where 3rd generation sfermions are much heavier than 1st/2nd generation sfermions **without inducing large FCNC**

↓

Higgs(+gaugino) mediation

[Yin, Yokozaki, 2016; Yanagida, Yin, Yokozaki, 2016, 2018]

Higgs mediation

Because of flavor constraints, we start with the sequestered Kahler potential

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

Z: SUSY breaking field

[Randall, Sundrum, 1999]

Q_i: MSSM field

Then, sfermions are massless

FCNC is suppressed!

But, of course massless sfermions are ruled out!

(If there are anomaly mediation effects, slepton masses are tachyonic)

We can couple Higgs doublets to SUSY breaking field without worrying about FCNC

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

$$\Delta K' = d' \frac{|Z|^2}{M_P^2}(H_u^\dagger H_u + H_d^\dagger H_d) - c_b \frac{|Z|^2}{M_P^2} H_u H_d + h.c.$$

d' is assumed to be positive **so that Higgs soft masses are tachyonic**

This is an important assumption

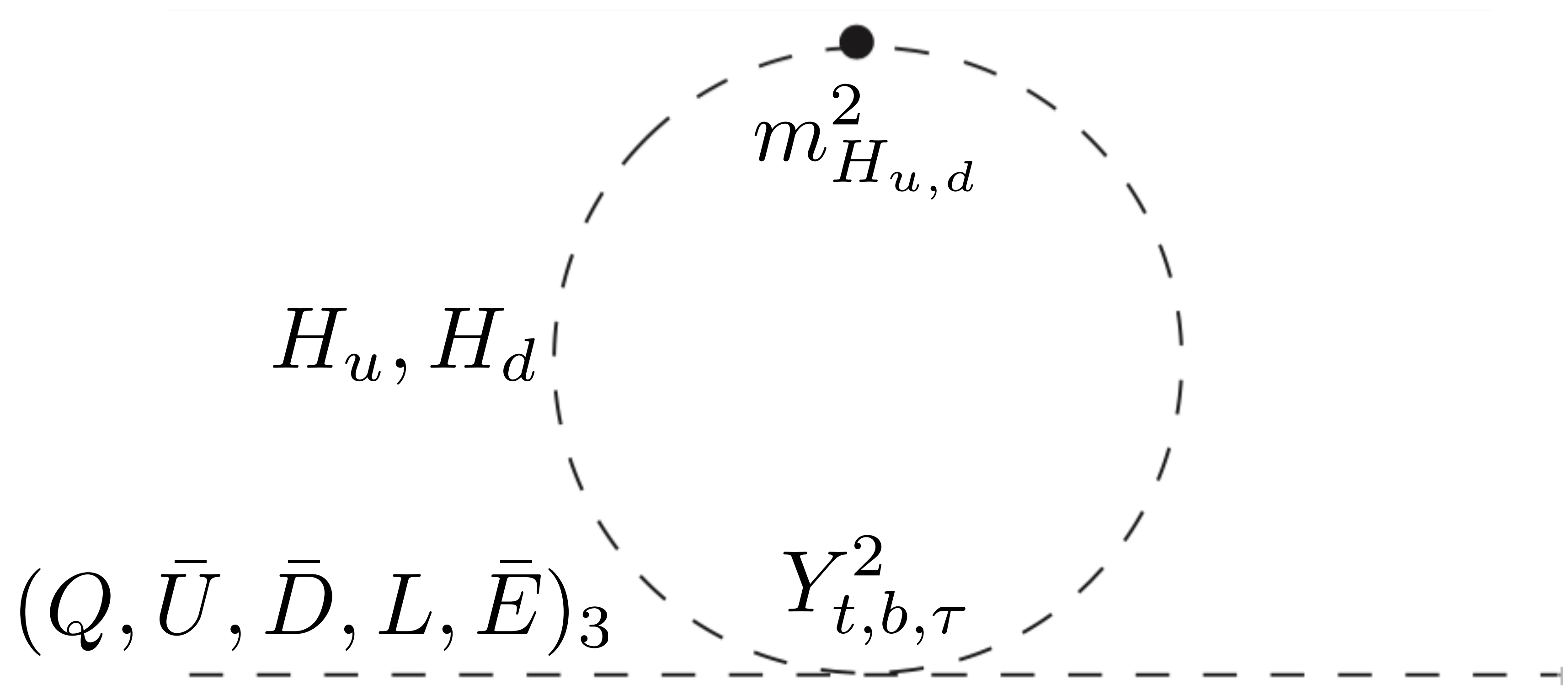
$$m_{H_u}^2 = m_{H_d}^2 = -d' \frac{|F_Z|^2}{M_P^2} = -3d' \left(\frac{\partial^2 K}{\partial Z \partial Z^\dagger}\right)^{-1} m_{3/2}^2$$

$\mathcal{O}(10^8\text{-}10^9)\ \mathrm{GeV}^2$

and the Higgs B-term

(D-flat direction is still safe with $|\mu|^2$ term)

Higgs loops



One-loop diagrams induce large positive squared masses for the third generation sfermions

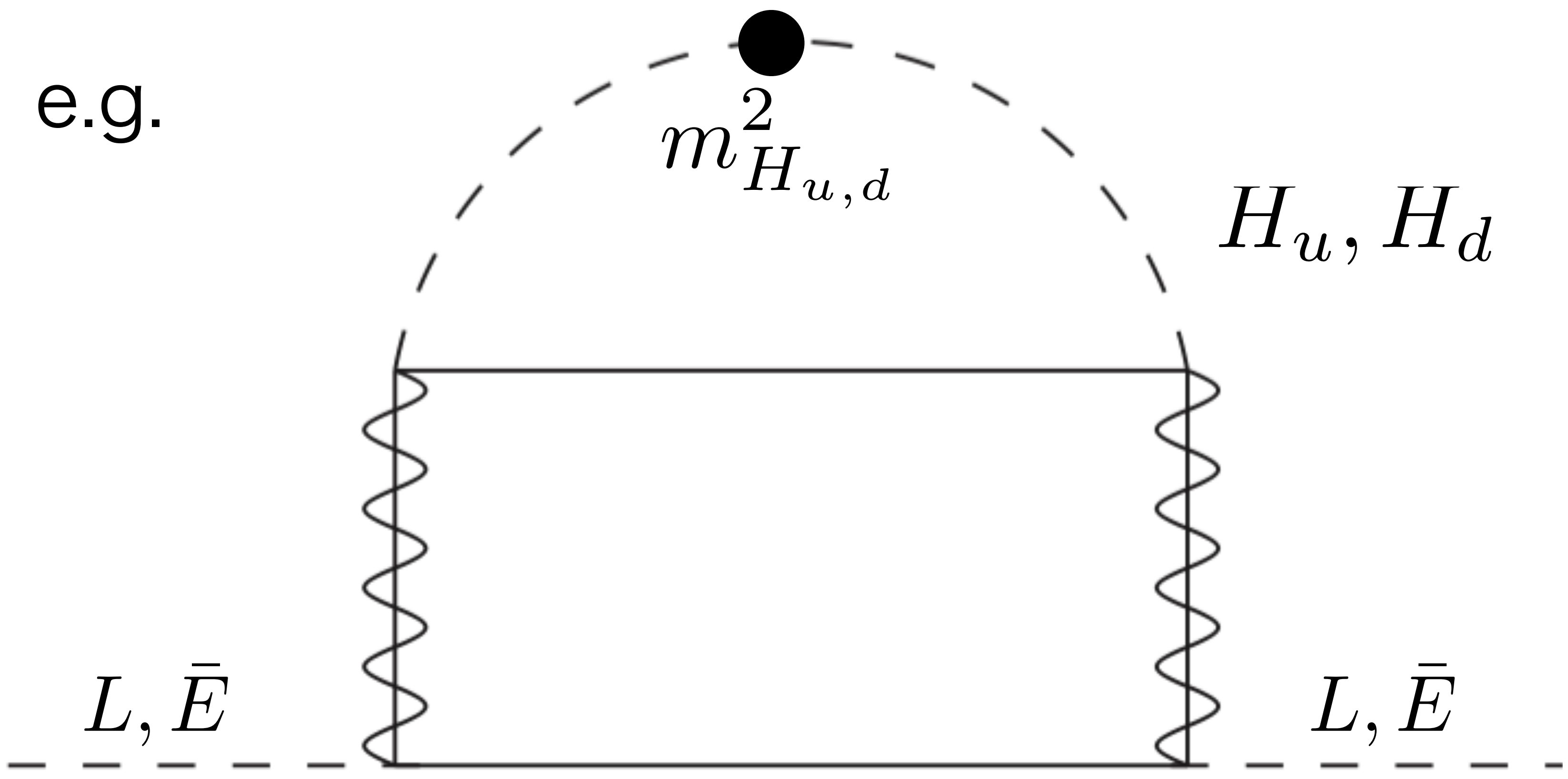
$$\frac{dm_3^2}{d\ln\mu_R} \ni \frac{1}{16\pi^2}\left(C_t Y_t^2 m_{H_u}^2 + C_b Y_b^2 m_{H_d}^2 + C_\tau Y_\tau^2 m_{H_d}^2\right) < 0$$

with $C_{t,b,\tau} \geq 0$

m_3 can be as large as ~10TeV

Higgs loops

e.g.



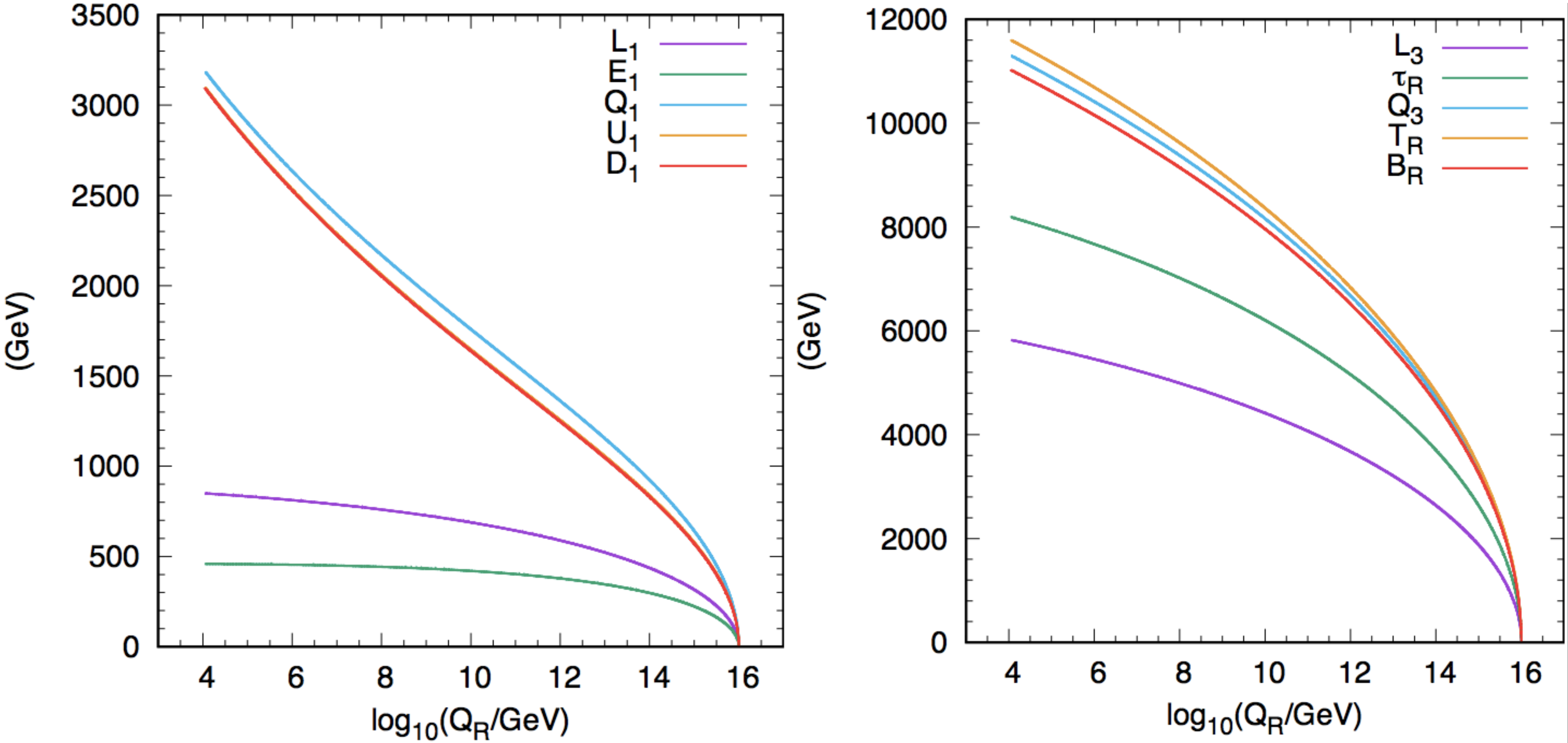
Two-loop diagrams induce positive slepton squared masses of O((100 GeV)^2)

(if it combines with anomaly mediation, tachyonic slepton problem is solved)

Consequently hierarchical sfermion masses are generated without inducing too large FCNC

$$m_3 \gg m_{1,2}$$

RGE flows in Higgs+gaugino mediation



$M_1 = 440\,\mathrm{GeV}, M_2 = 220\,\mathrm{GeV}, M_3 = -2000\,\mathrm{GeV}, m_{H_u}^2 = -7\times 10^8\,\mathrm{GeV}^2, \tan\beta = 40$

(mass parameters are set at the GUT scale)

SUSY breaking mediated by Higgs-loops

- Squarks and sleptons get masses from the Higgs soft masses, and the hierarchy originates from the structure of the Yukawa couplings

Higgs mediation

↕

- Quarks and leptons get masses from the Higgs VEV, and the hierarchy originates from the structure of the Yukawa couplings

Standard model

Dark matter

- Because of severe constraints from direct detection experiments (LUX, PandaX), we consider the purely bino-like LSP, so that neutralino-neutralino-Higgs coupling is suppressed

- Usually, the purely bino-like neutralino is overabundant

- Correct relic abundance is obtained via **bino-wino or bino-slepton coannihilations** when their masses are close to each other

- This can be achieved with **non-universal gaugino masses** together with Higgs mediation

Non-universal gaugino masses from product group unification

- In SUSY GUT models, there exists a serious fine-tuning problem: doublet-triplet splitting problem

- $SU(5) \times SU(3)_H \times U(1)_H$ model solves this problem elegantly

  [Yanagida, 1995; Hotta, Izawa, Yanagida, 1996]

- Non-universal gaugino masses naturally arise in this GUT model

- Gauge couplings (approximately) unify for large hidden gauge couplings

$U(1)_Y$: $$g_1^{-2} = g_5^{-2} + \mathcal{N}^{-1} g_{1H}^{-2},$$

$SU(2)_L$: $$g_2^{-2} = g_5^{-2},$$

$SU(3)_C$: $$g_3^{-2} = g_5^{-2} + g_{3H}^{-2},$$

The corrections can be small

For the gaugino masses, the relevant Lagrangian is

$$\mathcal{L} = \frac{1}{4g_5^2}\int d^2\theta \left(1 + 2\frac{k_5}{M_P}Z\right) W_5 W_5 + h.c.$$
$$+ \frac{1}{4g_{3H}^2}\int d^2\theta \left(1 + 2\frac{k_{3H}}{M_P}Z\right) W_{3H} W_{3H} + h.c.$$
$$+ \frac{1}{4g_{1H}^2}\int d^2\theta \left(1 + 2\frac{k_{1H}}{M_P}Z\right) W_{1H} W_{1H} + h.c.$$

⬇

$\simeq g_5^2/\mathcal{N}$

bino: $$M_1 = (k_5 \mathcal{N} + k_{1H}) \frac{g_5^2 g_{1H}^2}{g_5^2 + \mathcal{N} g_{1H}^2} \frac{F_Z}{M_P},$$

wino: $$M_2 = k_5 g_5^2 \frac{F_Z}{M_P},$$

$\simeq g_5^2$

gluino: $$M_3 = (k_5 + k_{3H}) \frac{g_5^2 g_{3H}^2}{g_5^2 + g_{3H}^2} \frac{F_Z}{M_P},$$

Results

Free parameters are

$$(M_1, M_2, M_3, m_H^2, \tan\beta)$$ @ GUT scale

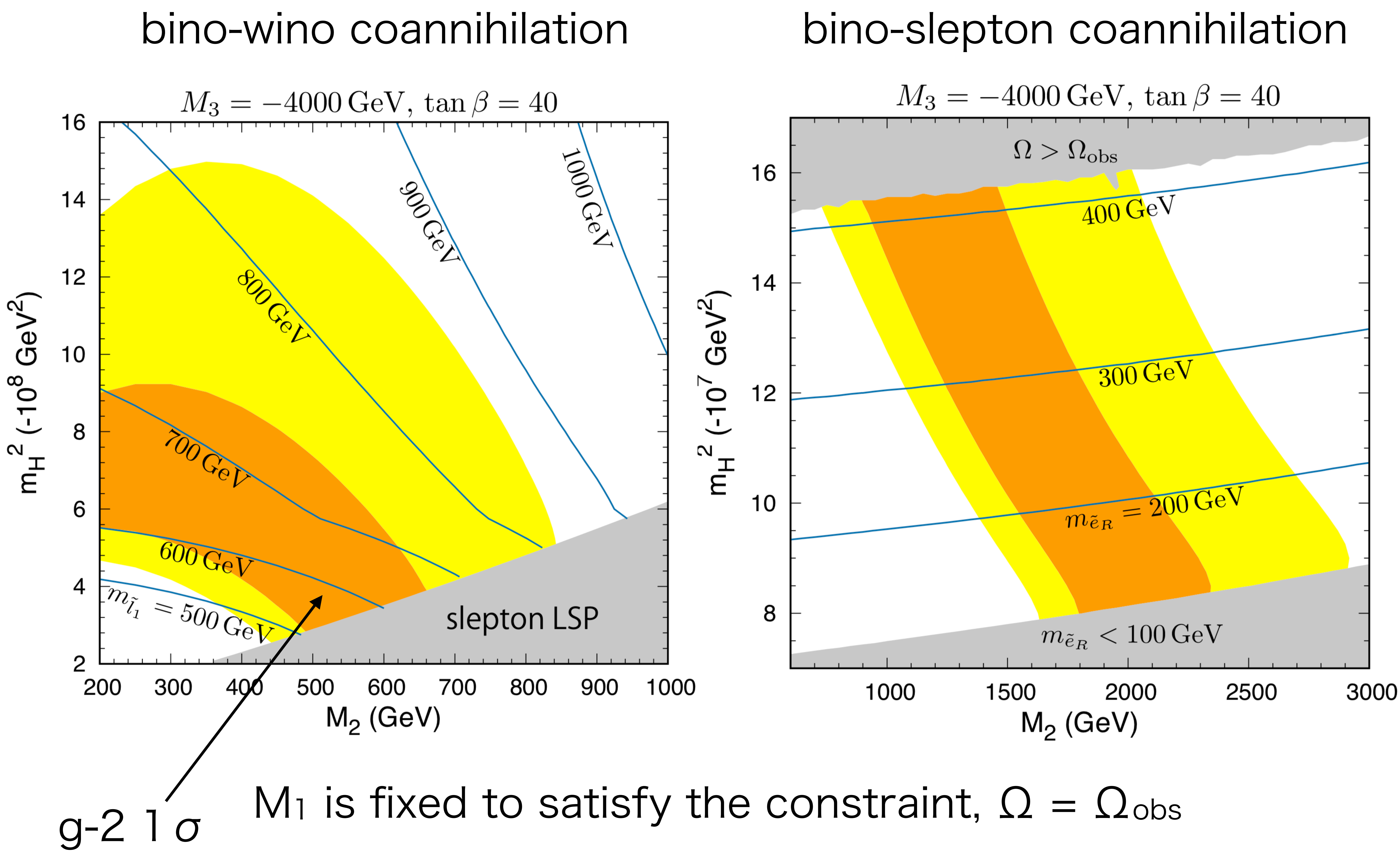
$$m_H^2 \equiv m_{H_u}^2 = m_{H_d}^2$$ <0

sfermions are massless at the GUT scale

We take $\mu > 0$

$$a_\mu^{\rm SUSY} = \left(1 - \frac{4\alpha}{\pi}\ln\frac{m_{\tilde{\mu}}}{m_\mu}\right)\left(\frac{1}{1+\Delta_\mu}\right) a_\mu^{\rm SUSY\text{-}1L}$$

dominant 2-loop corrections are included



M_1 is fixed to satisfy the constraint, $\Omega = \Omega_{\mathrm{obs}}$

$M_1 \approx M_2$ @low-energy scale $\qquad M_1 \approx m_{\tilde{e}_R}$

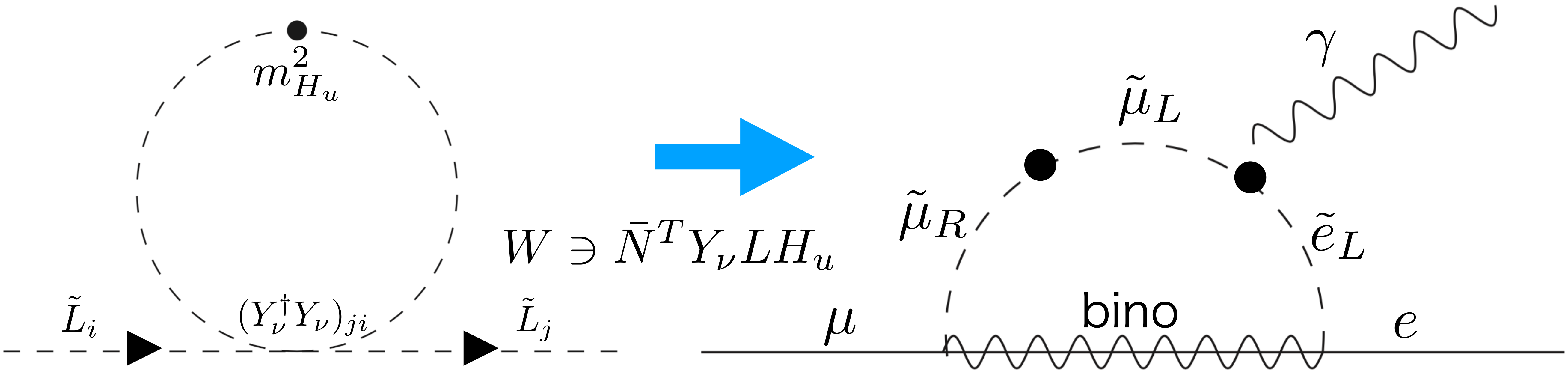
Mass spectrum

	BP1 $(\tilde{B}-\tilde{W})$	BP2 $(\tilde{B}-\tilde{l})$
$M_1(M_{\rm GUT})$	≈ 823	≈ 558
$M_2(M_{\rm GUT})$	400	1500
$M_3(M_{\rm GUT})$	-4000	-4000
$m^2_{H_u}=m^2_{H_d}(M_{\rm GUT})$	$-6.0\times10^8\,{\rm GeV}^2$	$-1.2\times10^8\,{\rm GeV}^2$
$\tan\beta$	40	40
$m_{\tilde{g}}$	8180	8050
$m_{\tilde{q}}$	6620	6700
$m_{\tilde{t}_1},\,m_{\tilde{t}_2}$	11900, 12100	7610, 7690
$m_{\tilde{e}_L},\,m_{\tilde{e}_R}$	680, 668	968, 287
$m_{\tilde{\mu}_L},\,m_{\tilde{\mu}_R}$	720, 746	976, 341
$m_{\tilde{\tau}_1},\,m_{\tilde{\tau}_2}$	5510, 7800	2720, 3660
$m_{\tilde{\nu}_e},\,m_{\tilde{\nu}_\mu},\,m_{\tilde{\nu}_\tau}$	676, 715, 5520	964, 973, 2740
$m_{\tilde{\chi}^0_1}$	404	283
$m_{\tilde{\chi}^\pm_1}\simeq m_{\tilde{\chi}^0_2}$	431	1370
$m_{\tilde{\chi}^\pm_2}\simeq m_{\tilde{\chi}^0_{3,4}}$	20900	9860
$m_A\simeq m_{H^0}\simeq M_{H^\pm}$	6800	2480
m_h	125.3	125.4
Δa_μ	2.64×10^{-9}	2.71×10^{-9}
$\Omega_{DM}h^2$	0.119	0.119

FeynHiggs 2.14.1 micrOMEGAs are used

Lepton flavor violations with RH-neutrinos

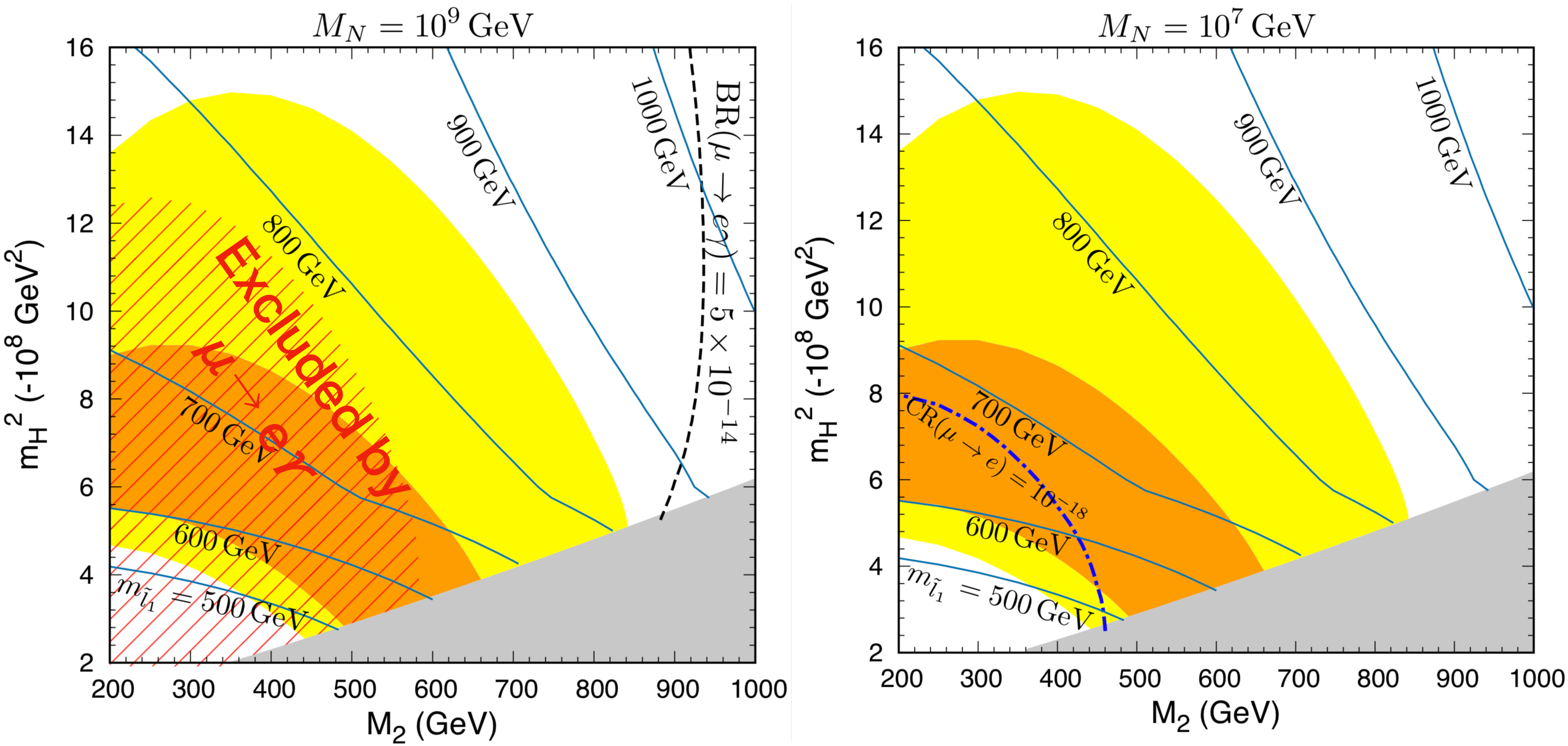
- Our scenario is flavor safe with the MSSM matter contents
- However, once RH-neutrinos are included, LFV processes are generated through slepton mass mixing



- We expect $M_N > 10^9$ GeV to reproduce a baryon asymmetry with thermal Leptogenesis [Davidson, Ibarra, 2002]

bino-wino coannihilation

$M_3 = -4000\text{GeV},\ \tan\beta = 40$



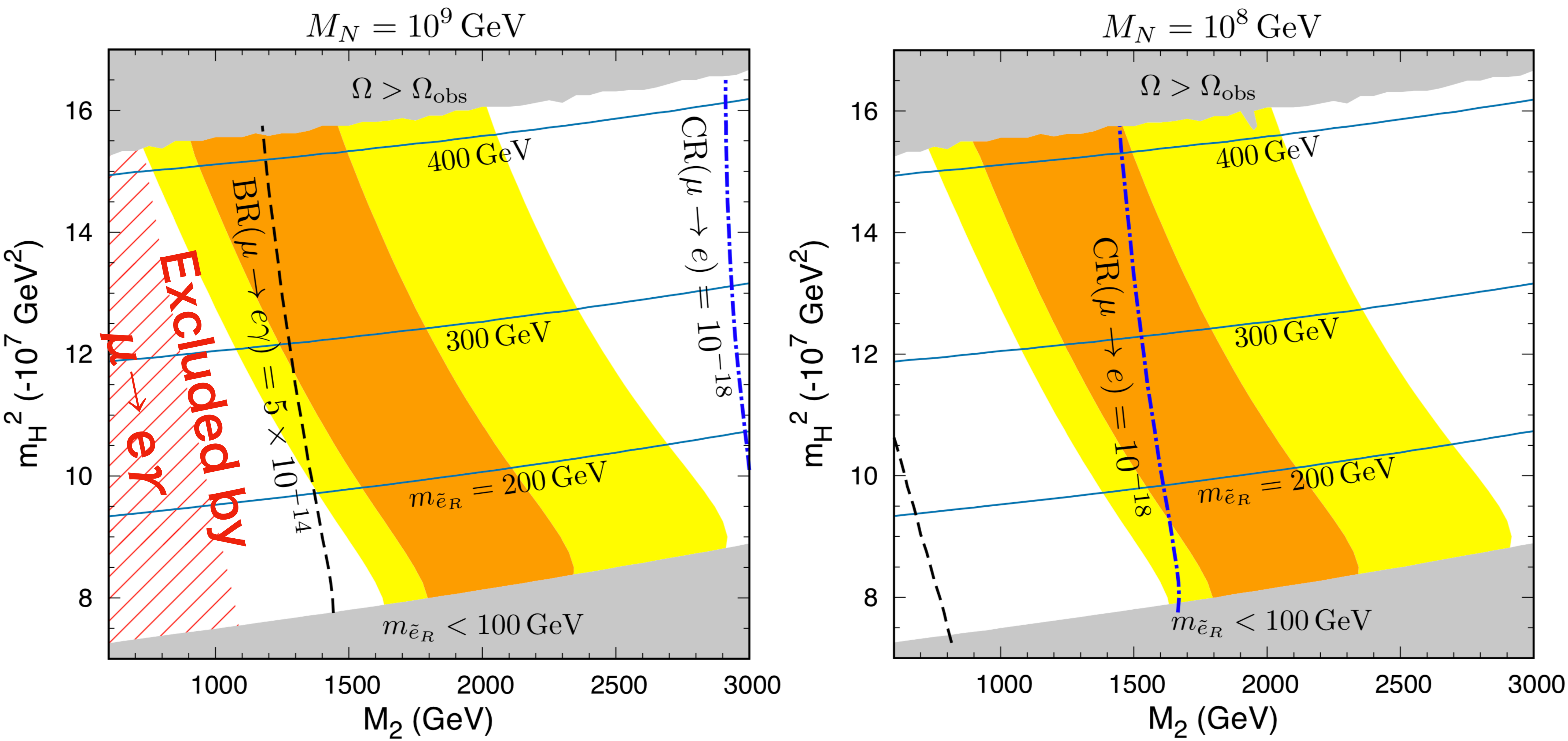
$\mu \to e\gamma$ can probe the scenario for $M_N = 10^9$GeV

μ-e conversion → $M_N = 10^7$GeV

(For degenerated RH neutrino masses)

bino-slepton coannihilation

$M_3 = -4000\text{GeV}, \tan\beta = 40$



μ-e conversion can probe the scenario for $M_N = 10^8$GeV

(For degenerated RH neutrino masses)

Summary

- In Higgs-gaugino mediation, the dark matter nature and the muon g-2 anomaly are explained simultaneously
- If RH-neutrinos are included and they are responsible for baryon asymmetry, sizable lepton flavor violations are induced
- Lepton flavor violations are expected to be checked in future experiments

Thank you for your attention