KAIST

Based on arXiv:1907.07168

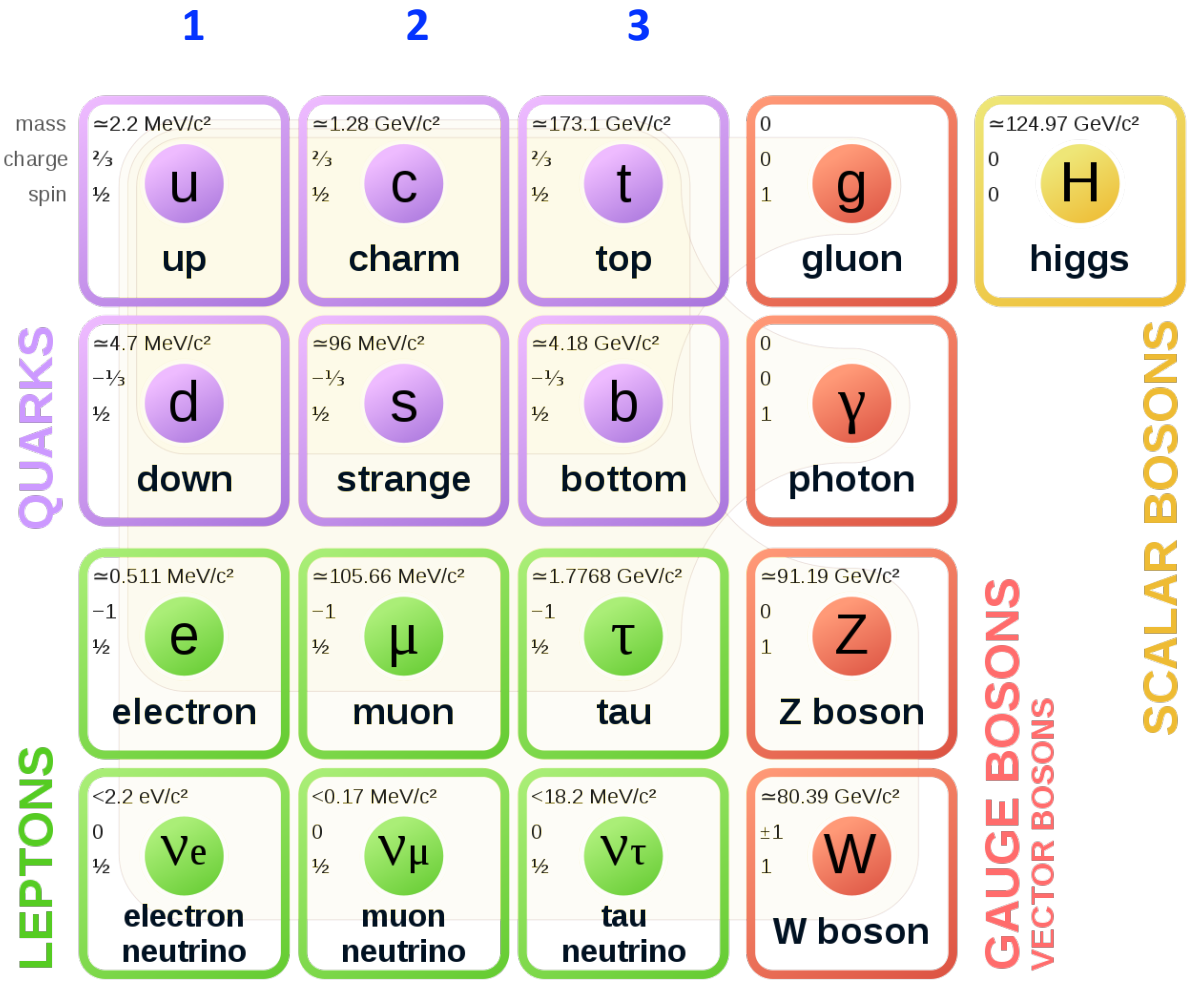
Dark matter coannihilation as a prediction of an origin of families and NLS miracle.

Wen Yin
KAIST

In collaboration with
N. Yokozaki, and T. T. Yanagida

20, Aug, 2019 @SI2019, Gangneung

1. Introduction



Why do we have three families?

Origin of families:
SUSY non-linear sigma (NLS) model

Kugo, Yanagida, 1984; Yanagida, Yasui, 1986

$$E_7 \xrightarrow{SSB} SU(5) \times U(1)^3$$

133 generators 27 generators

106 broken generators

$$SU(5)$$

$$T_a^I : \ \bar{\mathbf{5}},$$

$$T_I^{ab} : \ \mathbf{10},$$

$$T_I : \ 1,$$

$$T^a : \ \mathbf{5}$$

$$I = 1,2,3$$

106 NG multiplets

(SUSY relates fermions to NGBs)

$$(d, L) \times 3$$

$$(Q, u, e) \times 3$$

$$N_R \times 3$$

$$X$$

The origin of 3 families are explained.

What I will be talking about

Yokozaki, WY, Yanagida, 1907.07168

If the sfermions are pNGBs

$$\frac{Wino \text{ mass} - Bino \text{ mass}}{Bino \text{ mass}} < O(1\%)$$

Bino DM is predicted with coannihilation.

The origin of families can be tested in the LHC and future colliders.

2. Implication of the SUSY NLSM

If sfermions are pNGBS of Kahler manifold but Higgs multiplets are not:

See c.f. Refs. Komargodski, Seiberg, 1002.2228 ; Kugo, Yanagida, 1003.5985;

$$K \ni x + \frac{1}{2f_s^2}x^2 + (1 + c_u x)\,|H_u|^2 + (1 + c_d x)\,|H_d|^2 + \hat{c}_\mu H_u H_d + h.c. \cdots$$

$x = \phi_i^\dagger \phi_i + f_s S + f_s S^\dagger + \cdots$ ϕ_i : NG multiplets, *S*: singlet required for E_7 invariance

Assumptions to be realistic.

1. The SU(5) Gauge, and Higgs-Yukawa couplings break the E_7 symmetry explicitly. (like pions)

2. SUSY breaking field is charged under some symmetry and has small enough VEV. No polonyi problem, massless gauginos at tree-level.

Sorry for skipping many technical details.

Please ask me questions.

Gaugino mass spectra

We can derive the gaugino masses from the kahler potential, e.g. the wino mass at $\mu_{\rm RG} \simeq m_{3/2}$ scale is

$$M_2 \simeq \frac{g_2^2}{16\pi^2} m_{3/2} \left(1 + N_{\text{light pNGB doublets}} + (c_u + c_d)\right)$$

$$c_u \equiv \frac{A_u}{m_{3/2}} - 2, c_d \equiv \frac{A_{d,e}}{m_{3/2}} - 2,$$

$$N_{\text{light pNGB doublets}} = \underset{\tilde{Q}_i}{(3} + \underset{\tilde{L}_i}{1)} \times 3$$

Sorry for skipping many technical details.

Please ask me questions.

Gaugino mass spectra

We can derive the gaugino masses from the kahler potential, e.g. the wino mass at $\mu_{\rm RG} \simeq m_{3/2}$ scale is

Anomaly mediation

Giudice et al 9810442;

Randall, Sundrum, 9810155

$$M_2 \simeq \frac{g_2^2}{16\pi^2} m_{3/2} \left(1 + N_{\text{light pNGB doublets}} + (c_u + c_d) \right)$$

$$c_u \equiv \frac{A_u}{m_{3/2}} - 2, c_d \equiv \frac{A_{d,e}}{m_{3/2}} - 2,$$

$$N_{\text{light pNGB doublets}} = (3 + 1) \times 3$$

$\tilde{Q}_i$ $\tilde{L}_i$

Sorry for skipping many technical details.

Please ask me questions.

Gaugino mass spectra

We can derive the gaugino masses from the kahler potential, e.g. the wino mass at $\mu_{\rm RG} \simeq m_{3/2}$ scale is

Anomaly mediation

Giudice et al 9810442;
Randall, Sundrum, 9810155

Sigma-model anomaly mediation

Bagger et al, 9911029;

$$M_2 \simeq \frac{g_2^2}{16\pi^2} m_{3/2} \left(1 + N_{\text{light pNGB doublets}} + (c_u + c_d)\right)$$

$$c_u \equiv \frac{A_u}{m_{3/2}} - 2, c_d \equiv \frac{A_{d,e}}{m_{3/2}} - 2,$$

$$N_{\text{light pNGB doublets}} = (\underset{\tilde{Q}_i}{3} + \underset{\tilde{L}_i}{1}) \times 3$$

Sorry for skipping many technical details.

Please ask me questions.

Gaugino mass spectra

We can derive the gaugino masses from the kahler potential, e.g. the wino mass at $\mu_{\rm RG} \simeq m_{3/2}$ scale is

Anomaly mediation

Giudice et al 9810442;
Randall, Sundrum, 9810155

Sigma-model anomaly mediation

Bagger et al, 9911029;

$$M_2 \simeq \frac{g_2^2}{16\pi^2} m_{3/2} \left(1 + N_{\text{light pNGB doublets}} + (c_u + c_d) \right)$$

$$c_u \equiv \frac{A_u}{m_{3/2}} - 2, c_d \equiv \frac{A_{d,e}}{m_{3/2}} - 2,$$

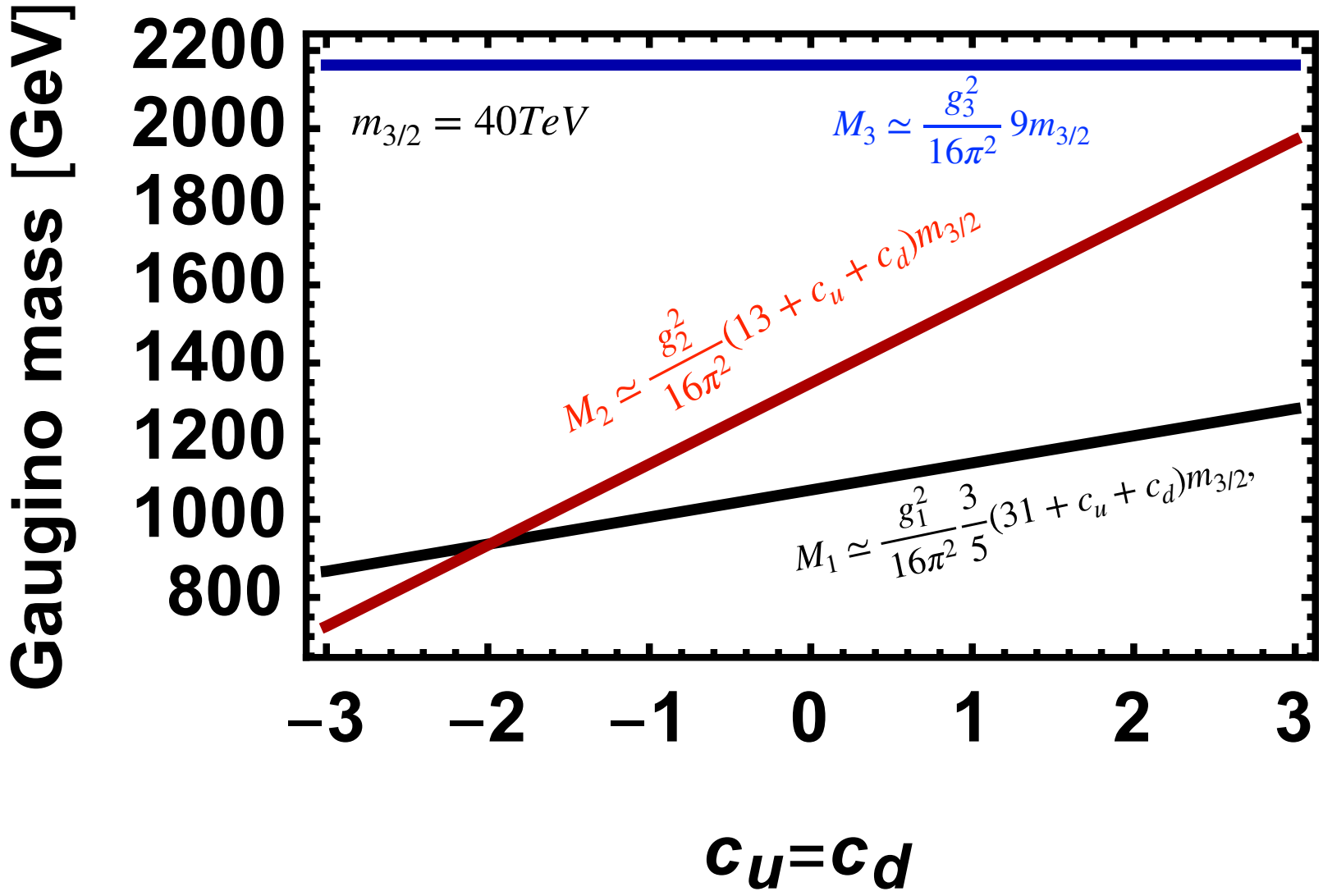
Fixed by non-linear realized symmetry

Yokozaki, WY, Yanagida, 1907.07168

i.e. Gaugino mass counts the (charged) pNGBs in the effective theory.

$$N_{\text{light pNGB doublets}} = \underset{\tilde{Q}_i}{(3} + \underset{\tilde{L}_i}{1)} \times 3$$

Gaugino mass spectra from the hypothesis: $\tilde{q}, \tilde{l}$=(p)NGBs



What is the typical value of c_u, c_d?

$$c_u \equiv \frac{A_u}{m_{3/2}} - 2, c_d \equiv \frac{A_{d,e}}{m_{3/2}} - 2,$$

Vacuum stability condition: Riotto, Roulet, 9512401;

$$7.5(m_{\tilde{Q}_3}^2 + m_{\tilde{u}_3}^2) \gtrsim 3\mu^2 + m_{3/2}^2(c_u + 2)^2$$

l.h.s : stop (=pNGB) masses which are *suppressed*.

They are generated due to the Higgs loop effect via large and negative Higgs masses, and thus the Higgs boson mass can be explained.

Yamaguchi, WY, 1606.04953

What is the typical value of c_u, c_d?

$$c_u \equiv \frac{A_u}{m_{3/2}} - 2, c_d \equiv \frac{A_{d,e}}{m_{3/2}} - 2,$$

Vacuum stability condition: Riotto, Roulet, 9512401;

$$7.5(m_{\tilde{Q}_3}^2 + m_{\tilde{u}_3}^2) \gtrsim 3\mu^2 + m_{3/2}^2(c_u + 2)^2$$

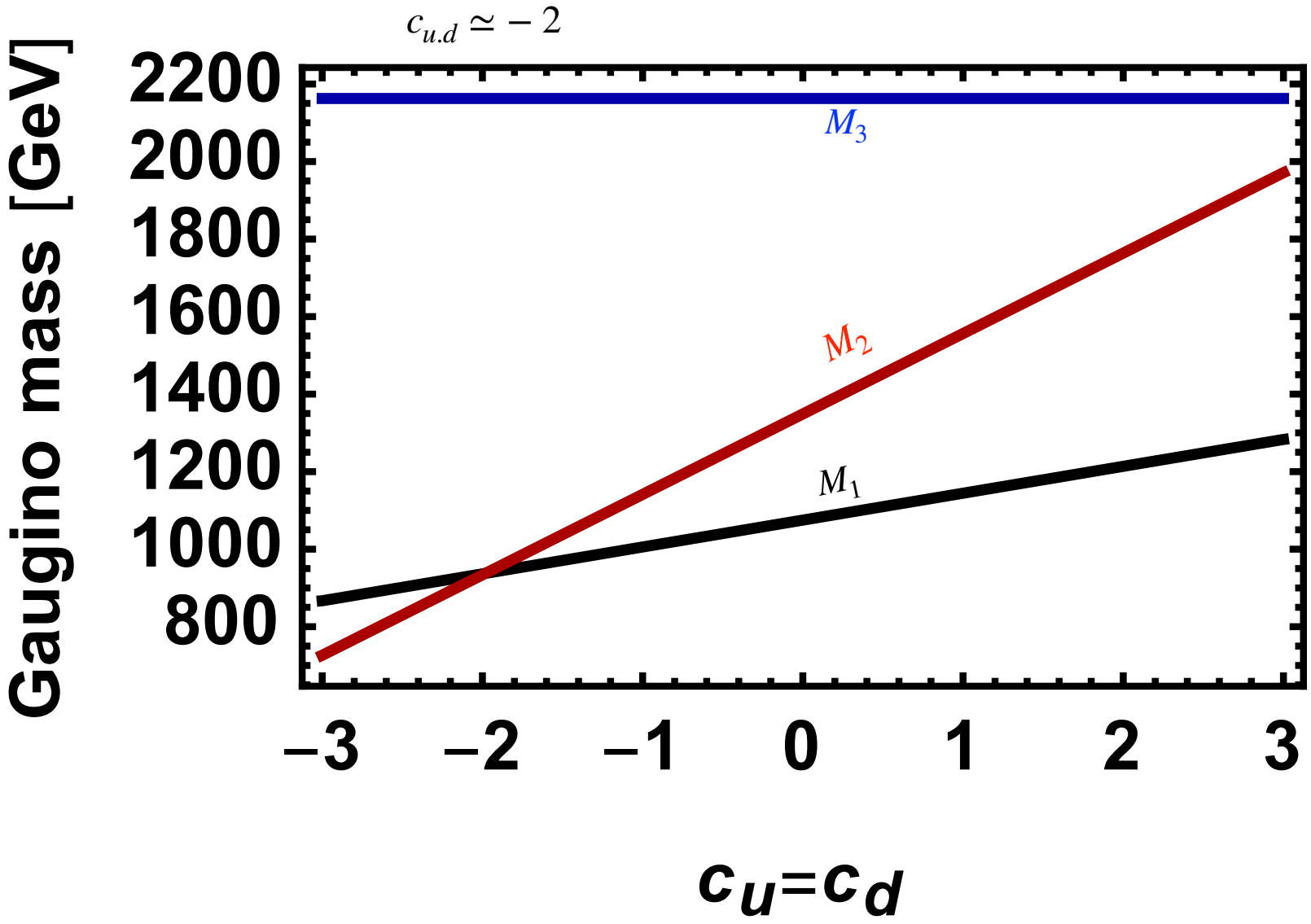
l.h.s : stop (=pNGB) masses which are *suppressed*.

They are generated due to the Higgs loop effect via large and negative Higgs masses, and thus the Higgs boson mass can be explained.

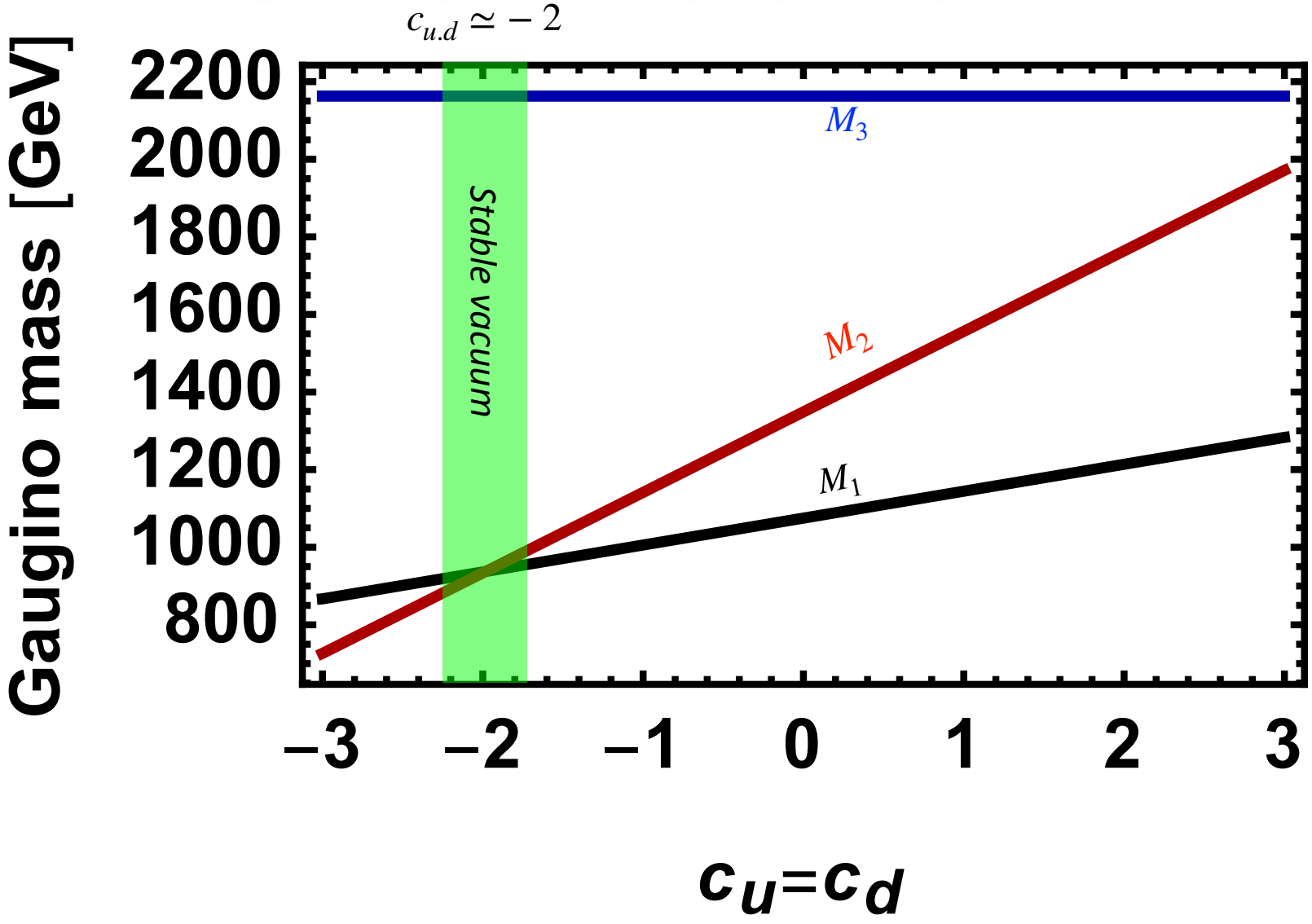
Yamaguchi, WY, 1606.04953

$$c_u \simeq -2$$

similar discussion leads $c_d \simeq -2$

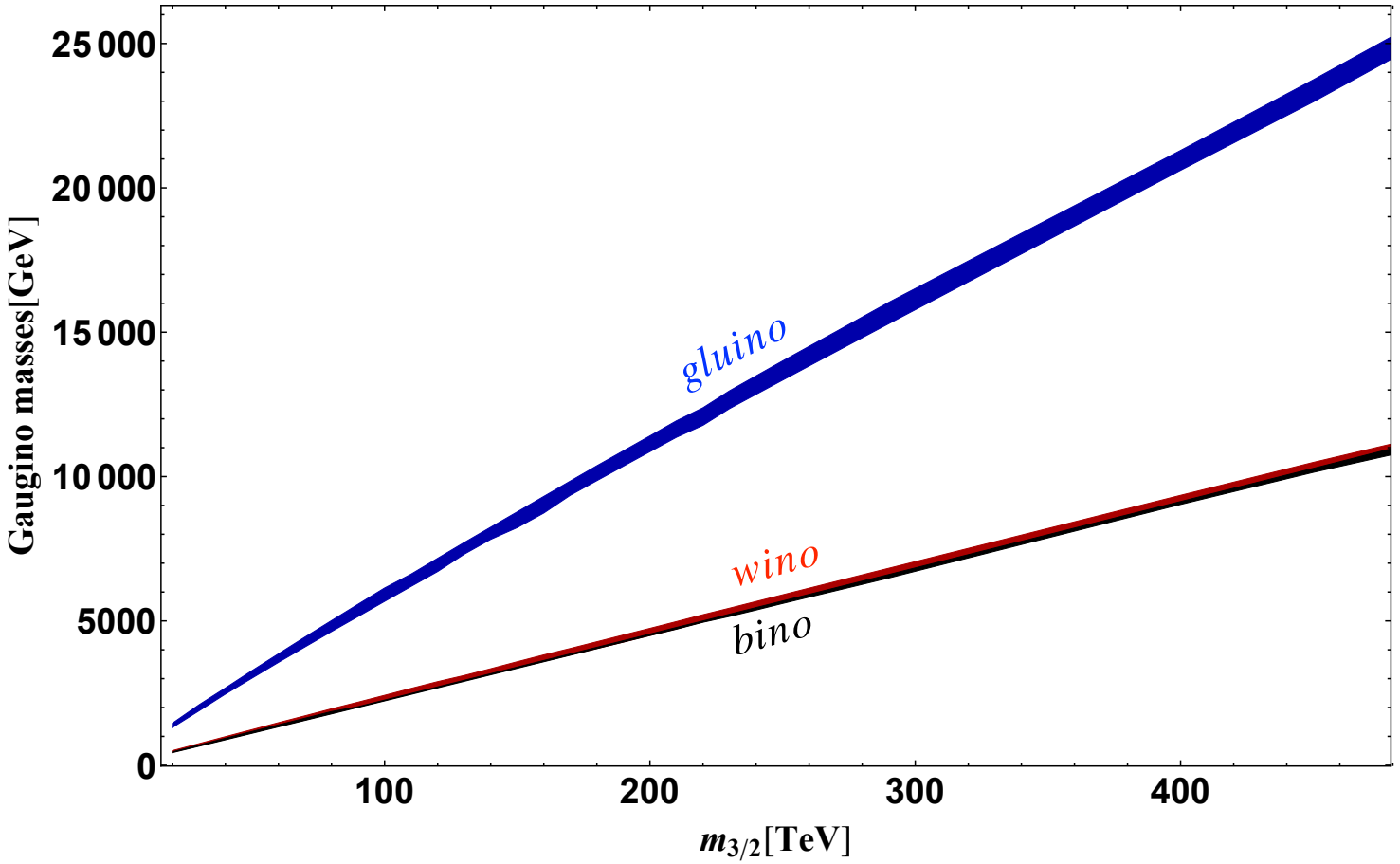

$c_{u.d} \simeq -2$
Gaugino mass [GeV]
2200
2000
1800
1600
1400
1200
1000
800
M_3
M_2
M_1
−3
−2
−1
0
1
2
3
$c_u = c_d$

Bino-Wino coannihilation!



Light gluino and squarks

With threshold corrections, bino mostly becomes the LSP.

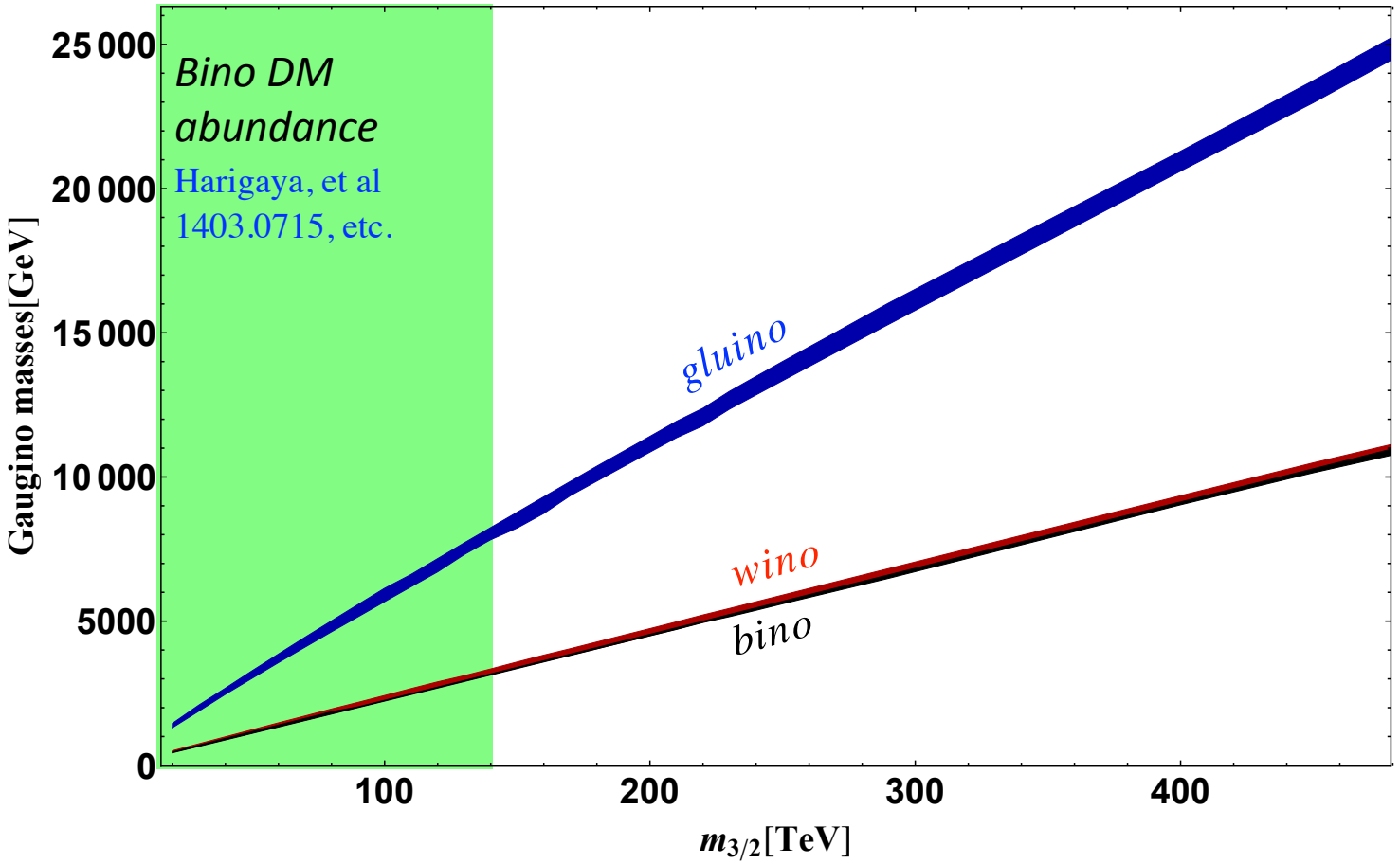


Light gluino and squarks can be tested in LHC and future colliders.

Wino can be also tested from precision measurement, see Chigusa's talk

Light gluino and squarks

With threshold corrections, bino mostly becomes the LSP.

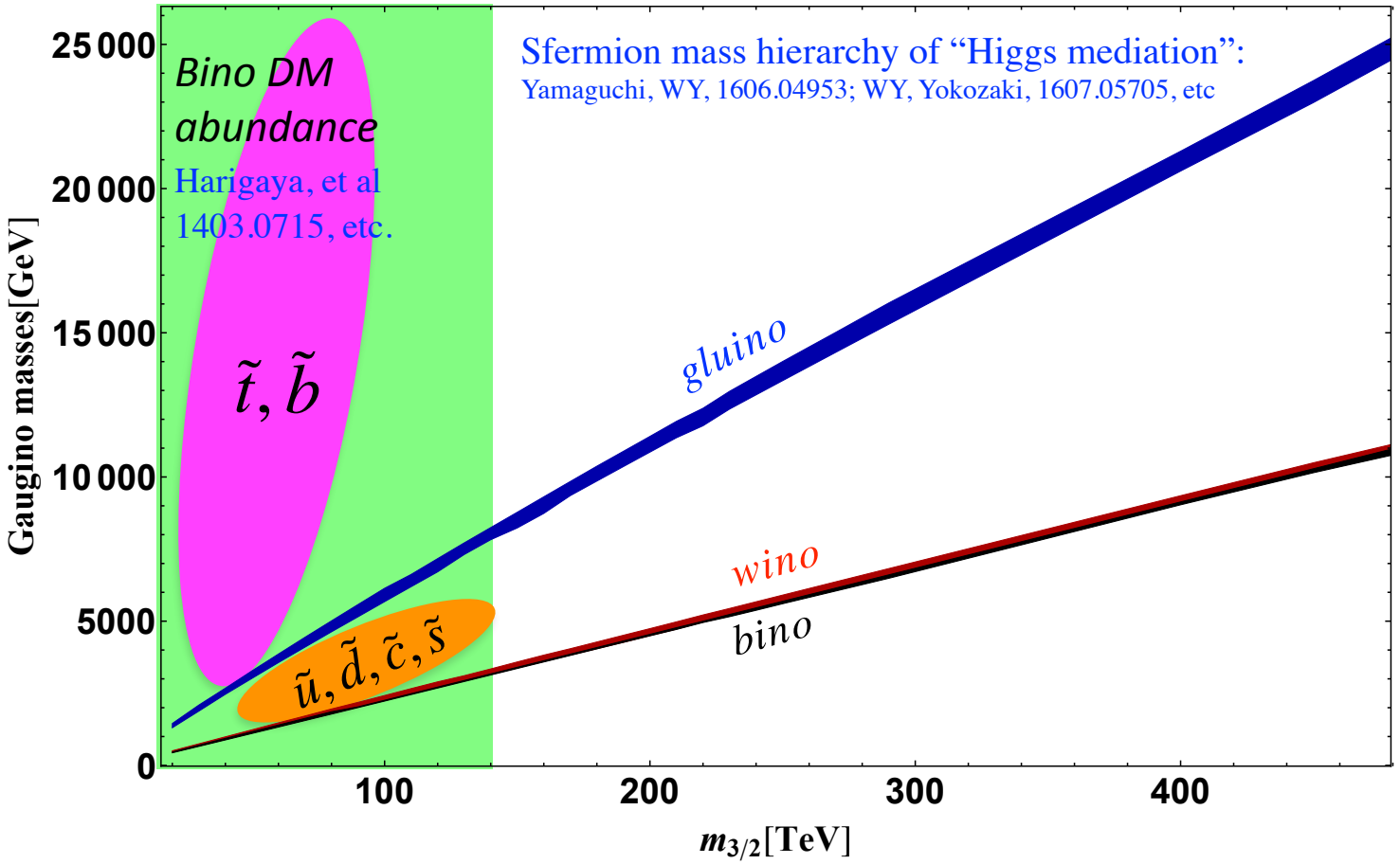


Light gluino and squarks can be tested in LHC and future colliders.

Wino can be also tested from precision measurement, see Chigusa's talk

Light gluino and squarks

With threshold corrections, bino mostly becomes the LSP.



Light gluino and squarks can be tested in LHC and future colliders.

Wino can be also tested from precision measurement, see Chigusa's talk

Summary

Yokozaki, WY, Yanagida, 1907.07168

$E_7/SU(5) \times U(1)^3$ SUSY nonlinear sigma model explains the origin of family.

We find

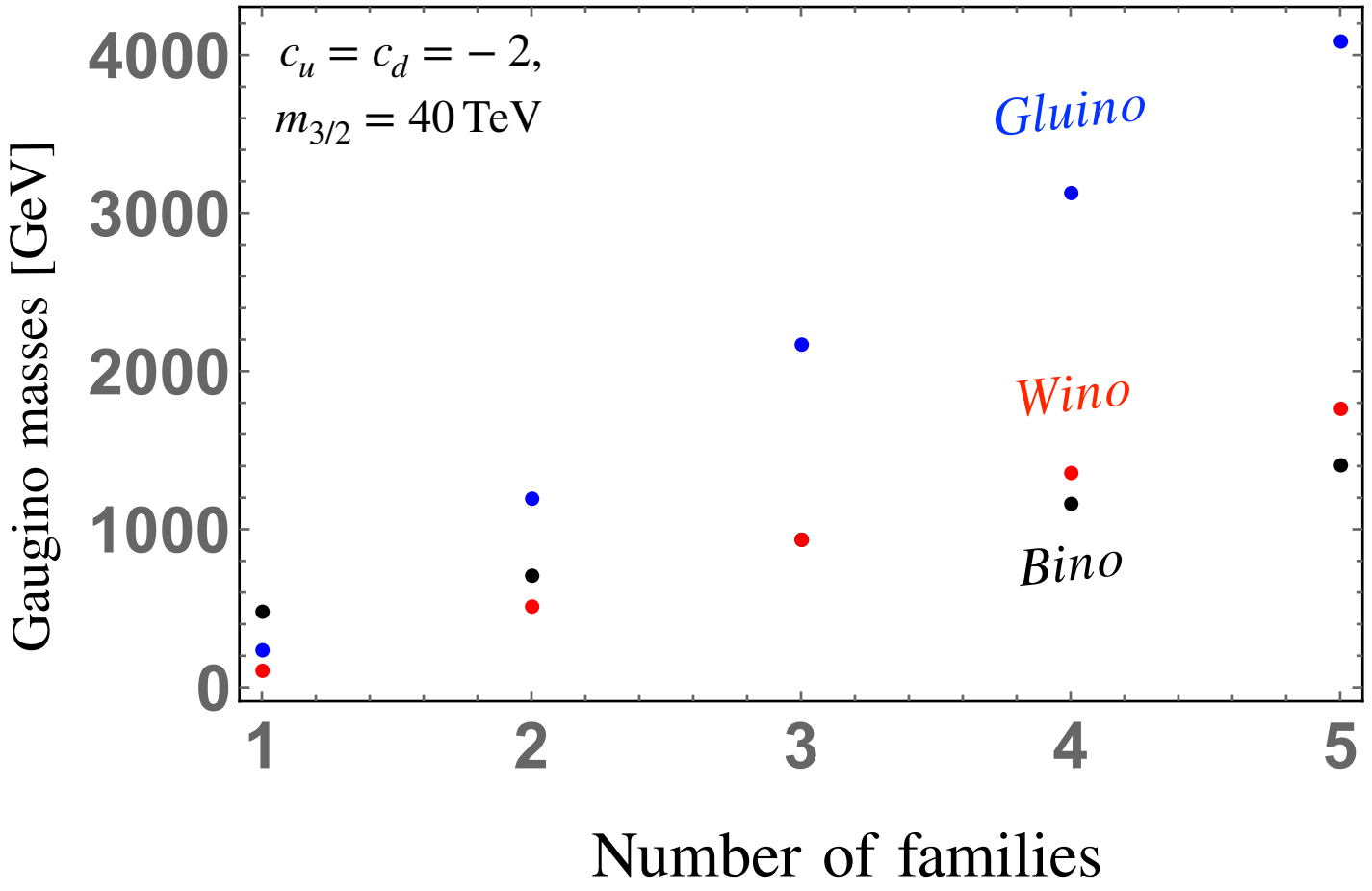
- Bino-wino are quasi degenerate within O(1)%, and thus bino DM is successful.
- Fully tested in the LHC and future colliders.

The family is important for our Mom.

(Check our paper or ask me.)

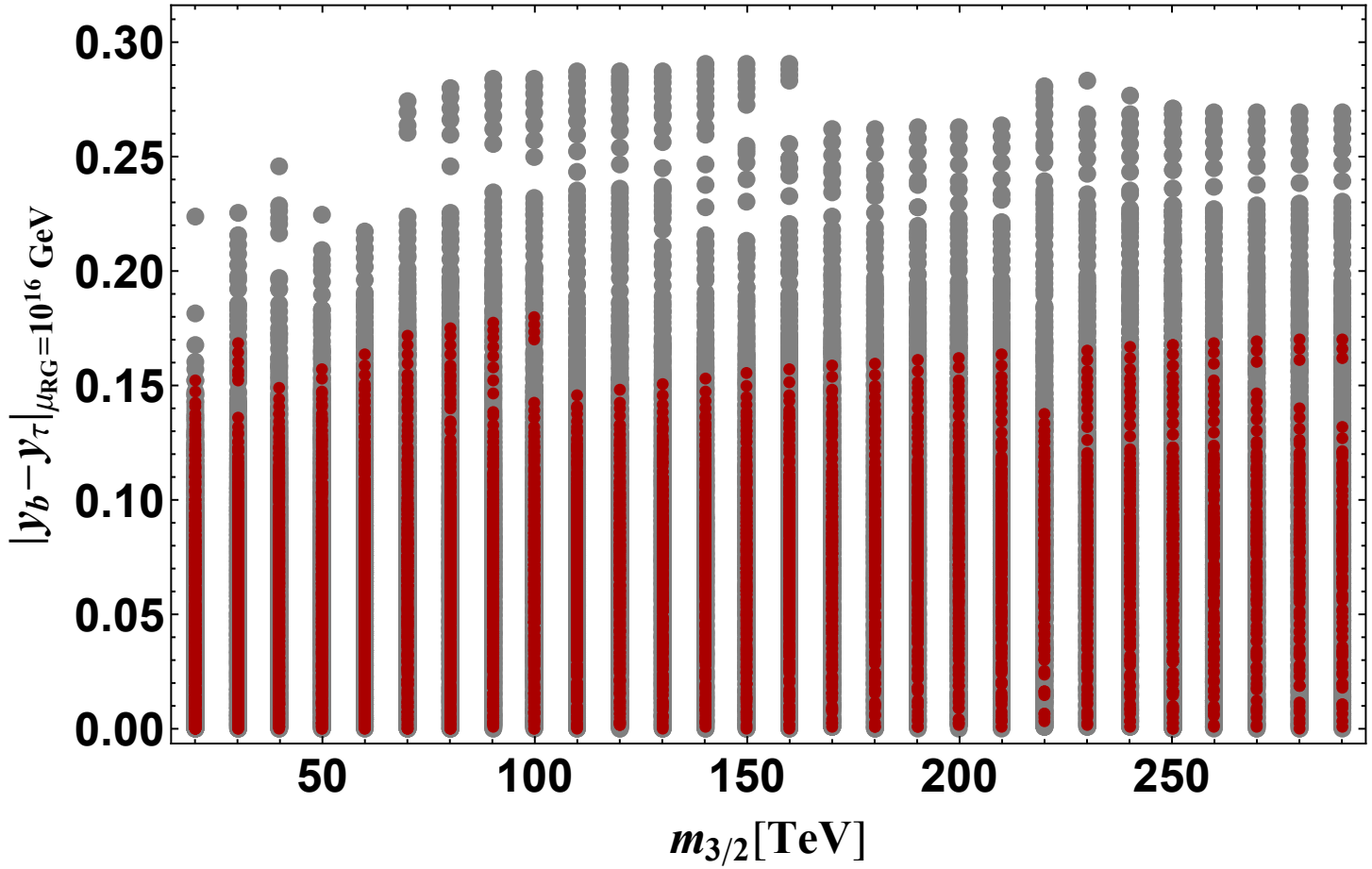
- $b - \tau$ Yukawa coupling unification at O(1)%.
- There is also a candidate of QCD axion.

The family is important for our Mom.

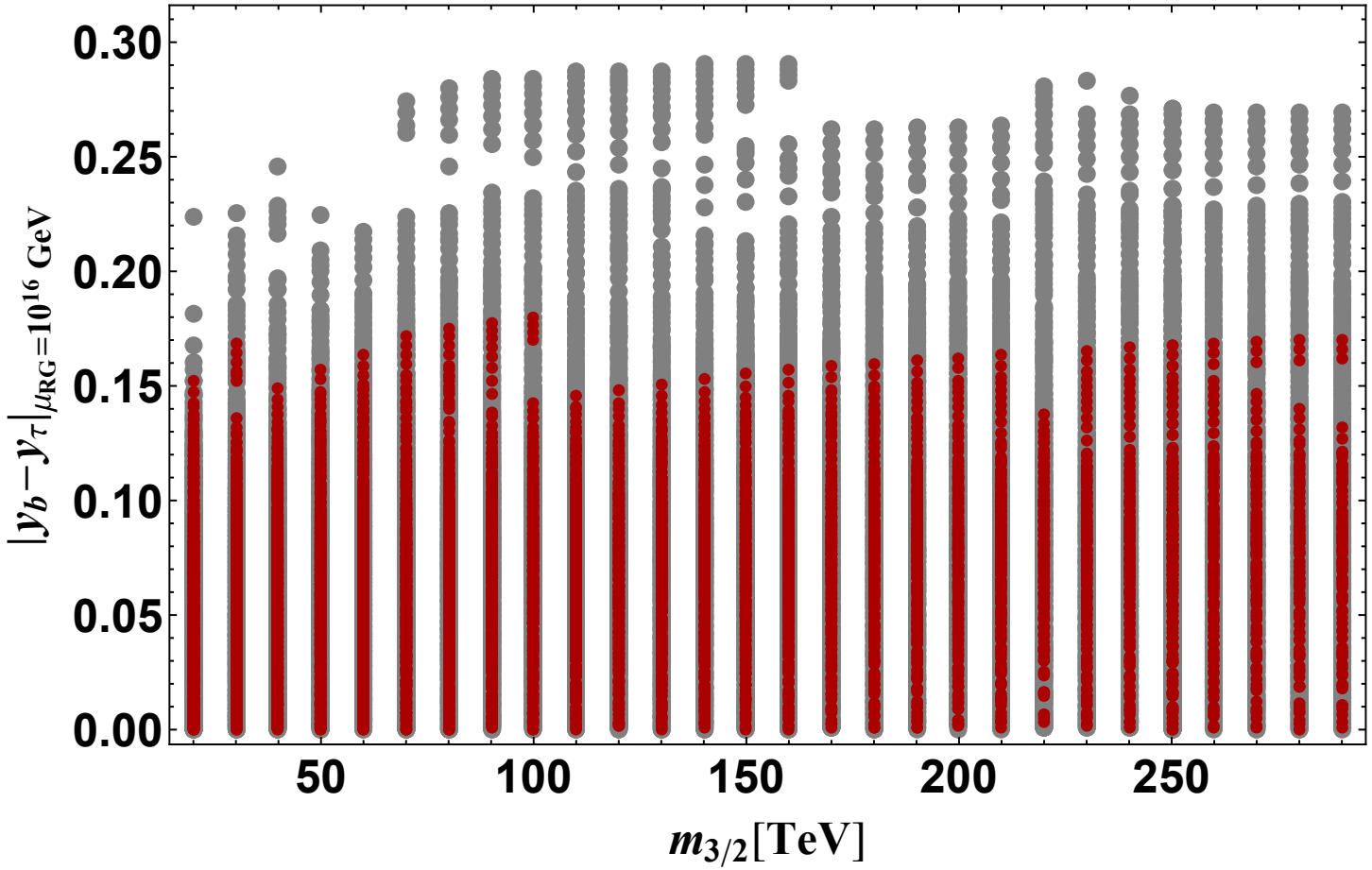


Data Points

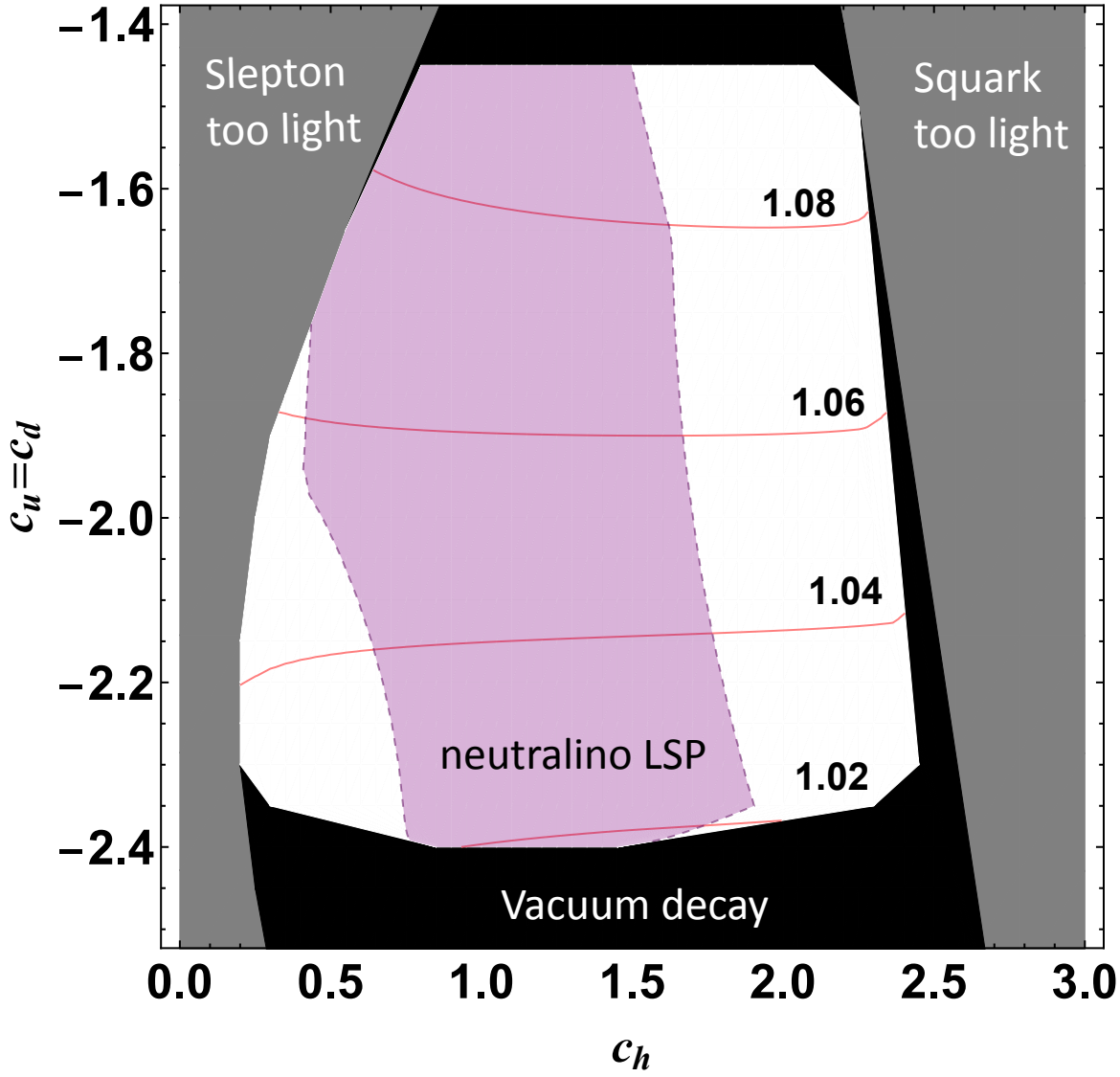
Parameters	**I**	**II**	**III**
$m_{3/2}$[TeV]	60	70	130
$\tan\beta$	53	49	50
c_h	0.84	1.7	0.6
$c_u = c_d$	-2.4	-2.3	-1.8
$\delta^{\rm axion} M_{1,2,3}/m_{3/2}$	0	0	-0.003
spectrum	[TeV]	[TeV]	[TeV]
χ_1	1.33	1.56	2.74
χ_2	1.36	1.59	2.74
$\tilde{g}$	3.81	4.38	6.64
$\chi_{3,4}$	48	79	87
$\tilde{u}, \tilde{c}, \tilde{d}, \tilde{s}$	2.2-2.8	1.7-3.3	3.7-4.9
$\tilde{t}, \tilde{b}$	21-22	32-36	40-42
$\tilde{\mu}, \tilde{e}$	1.5-2.3	1.7-3.6	2.8-4.3
$\tilde{\tau}_{1,2}$	15,22	23,33	27,38
$h_{\rm SM}$ [GeV]	122	124	124
couplings at $\mu_{\rm RG} =$	10^{16} GeV	10^{16} GeV	10^{16} GeV
y_b	0.58	0.42	0.58
y_τ	0.65	0.51	0.60
g_1, g_2, g_3	$\simeq 0.69$	$\simeq 0.69$	$\simeq 0.69$


0.30
0.25
0.20
0.15
0.10
0.05
0.00
50
100
150
200
250
$|y_b - y_\tau|_{\mu_{RG}=10^{16}\,GeV}$
$m_{3/2}$[TeV]

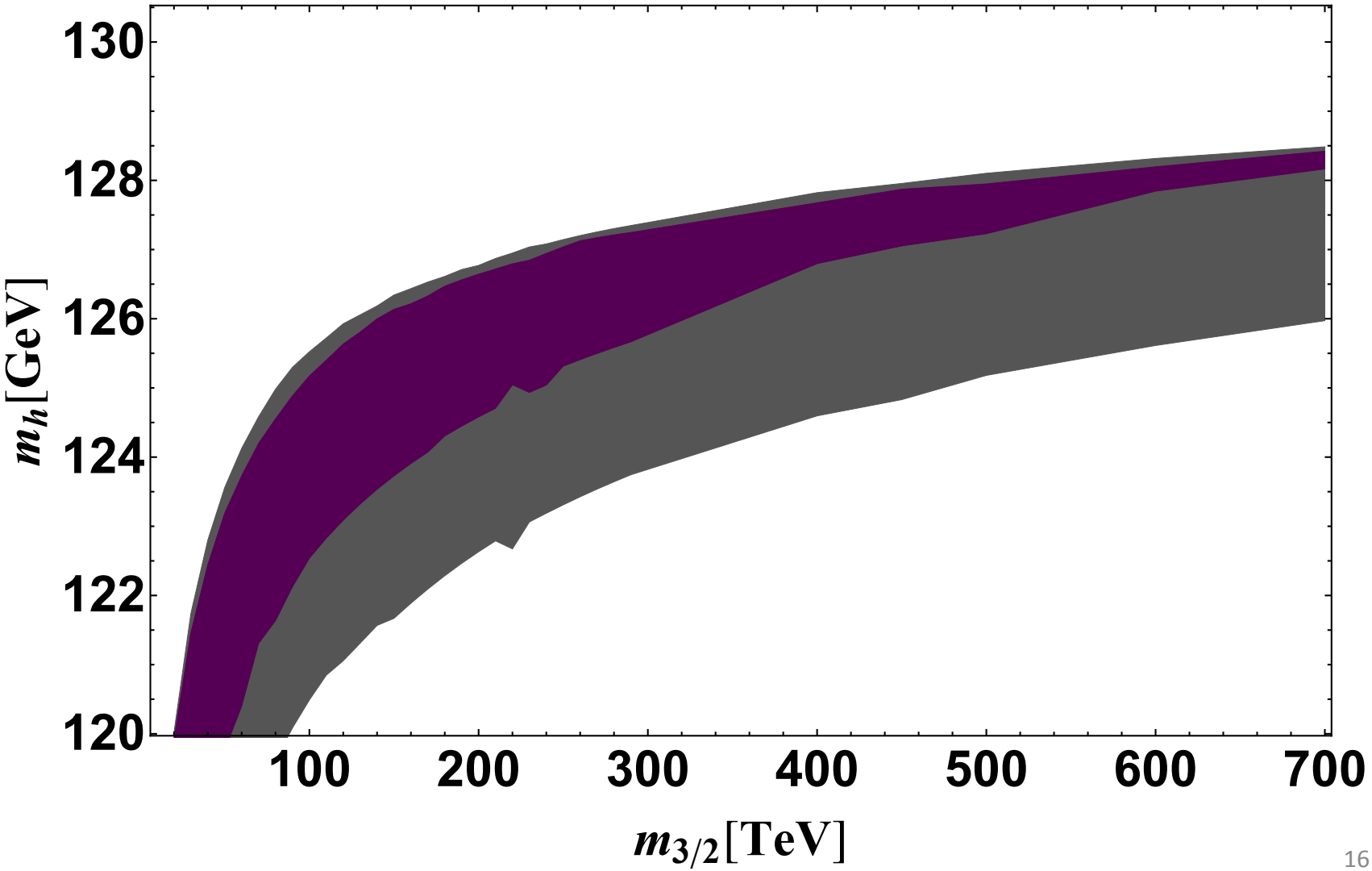
Yukawa coupling unification



Lightest chargino mass/Lightest neutralino mass



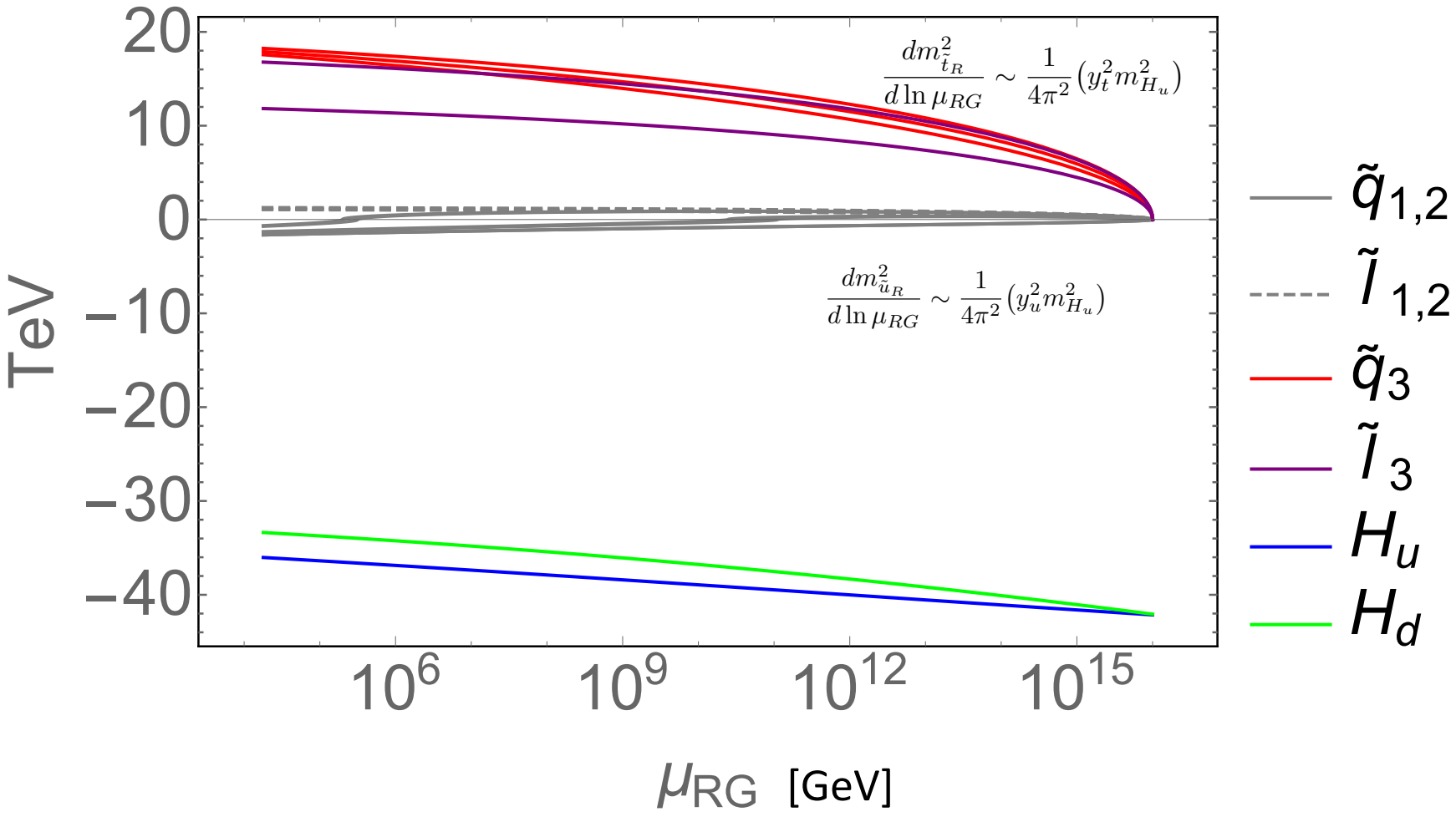
SM Higgs boson mass



Higgs Mediation

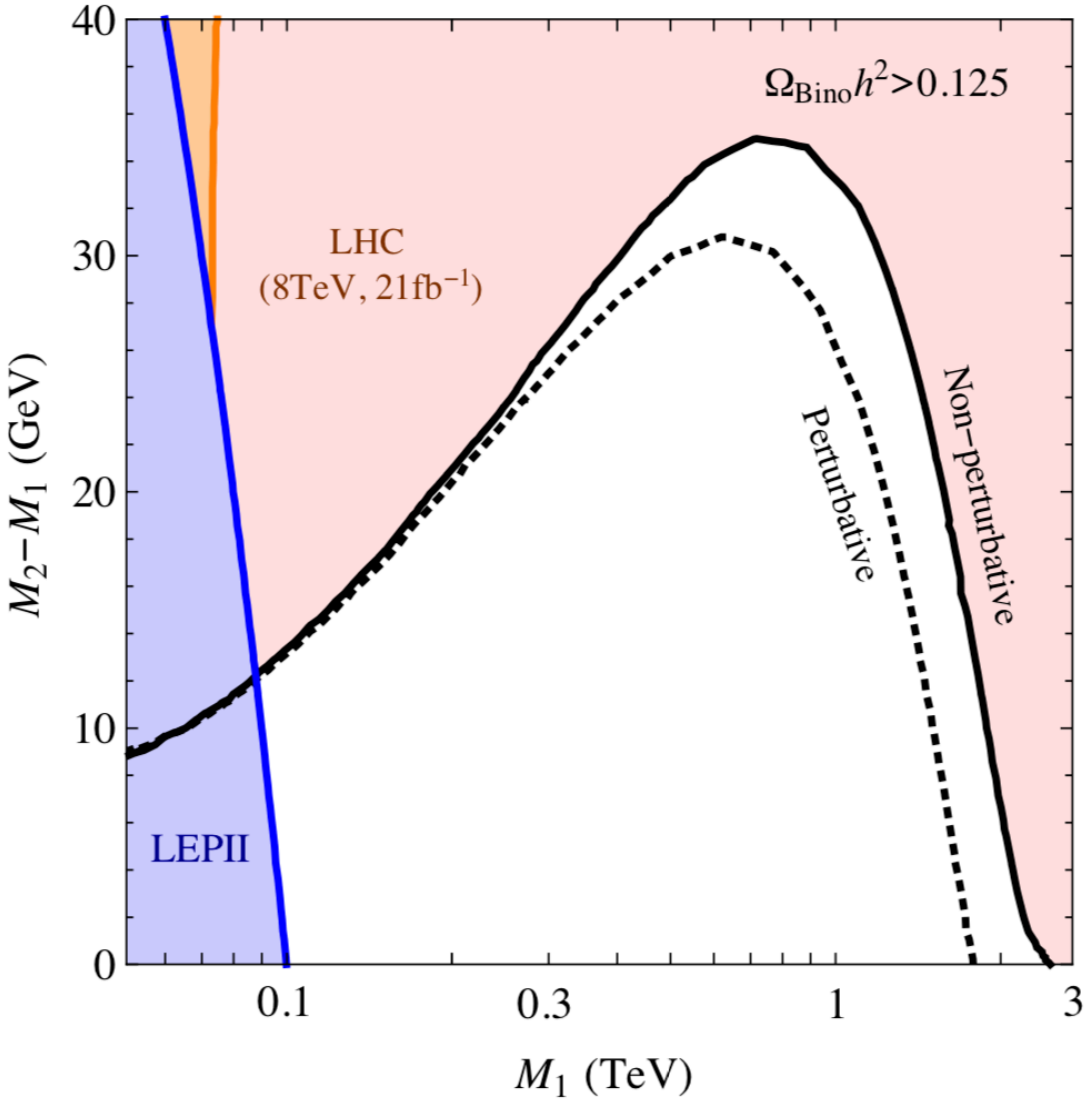
Yamaguchi, WY, 1606.04953

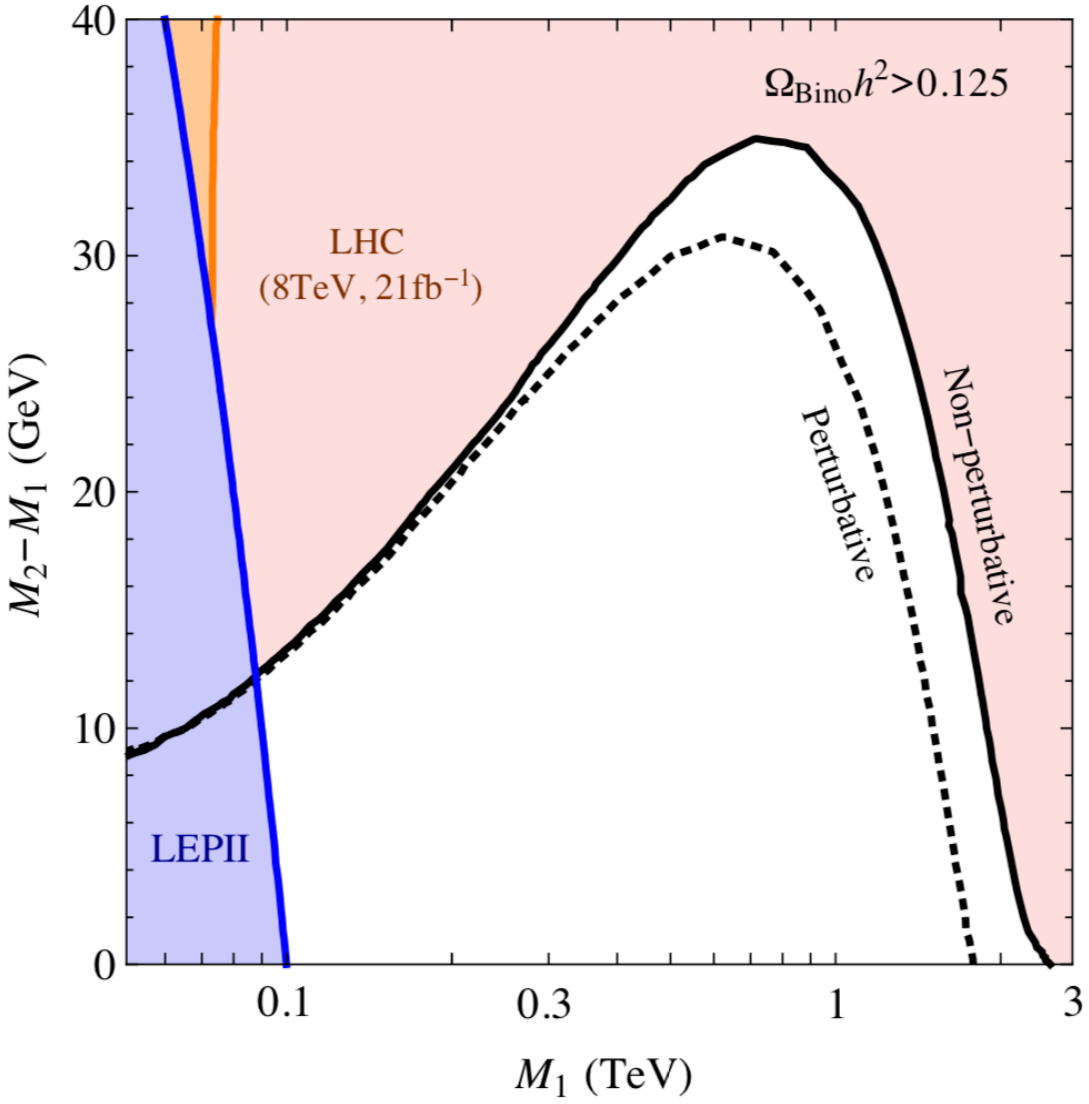
Radiative correction from Higgs multiplets: tanb=51



Splitting mass spectrum is obtained between generations due to 1loop RGE.

Bino abundance from coannihilation



Bino abundance from coannihilation

Harigaya, Kaneta and Matsumoto, 1403.0715