SUSY2016 @ Melbourne

Constraints on non-universal gaugino mass scenario using the latest LHC data

PTEP 2013 (2013) 013B02

PRD 93 (2016) no.5, 055019

Junichiro Kawamura

Waseda Univ.

with

Y.Omura (KMI, Nagoya Univ.)

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PTEP 2013 (2013) 013B02

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Please see also:

J,K. and Y.Omura

“Diphoton excess at 750 GeV and LHC constraints in models with vectorlike particles”

Phys.Rev. D93 (2016) no.11, 115011

Junichiro Kaw

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Y.Omura (KMI, Nagoya Univ.)

little hierarchy problem

Higgs mass and SUSY search indicate high-scale SUSY

→ **hierarchy between SUSY scale and EW scale**

- **minimization condition of the Higgs potential**

$$m_Z^2 \simeq -2\,|\mu|^2 + 2|m_{h_u}^2|$$

EW scale **SUSY scale**

- ✓ **fine-tuning is required if** $m_Z \ll \mu,\ m_{h_u}$
- ✓ **at least** $\mu(m_Z)$ **must be small since it's unique SUSY parameter**
- ✓ **small** $\mu(m_Z)$ **means small** $m_{H_u}(m_Z)$

Higgs mass vs little hierarchy

little hierarchy problem relates to the Higgs mass

☐ RGE of m_{h_u}

$$16\pi^2 \frac{dm_{h_u}^2}{dt} \simeq 6y_t^2\left(m_{h_u}^2 + m_{\tilde{t}_L}^2 + m_{\tilde{t}_R}^2 + A_t^2\right) - 6g_2^2|M_2|^2 - \frac{6}{5}g_1^2|M_1|^2$$

- top squark parameters $m_{\tilde{t}_L}^2, m_{\tilde{t}_R}^2, A_t$ appear
- heavier top squark leads severer fine-tuning
- top squark mass is crucial for the Higgs mass

✓ **10 TeV top squark forces 10^{-3} % tuning**

maximal mixing

☐ MSSM Higgs boson mass

$$m_h^2 \simeq m_Z^2 \cos^2 2\beta + \frac{3m_t^4}{8\pi^2 v_u^2}\left[\log\frac{M_{stop}^2}{m_t^2} + \frac{2A_t^2}{M_{stop}^2}\left(1 - \frac{A_t^2}{12M_{stop}^2}\right)\right]$$

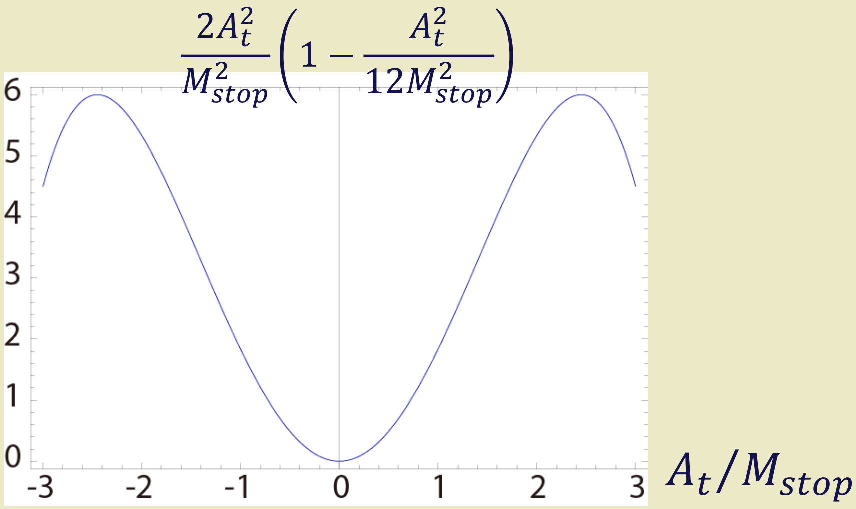
- $M_{stop} \simeq 10$ **TeV if** $A_t/M_{stop} \ll 1$
- **Higgs mass requires severer bound than direct SUSY search**

☐ maximal mixing scenario

the last term is maximized at

$$A_t/M_{stop} \sim \sqrt{6}$$

“maximal mixing”



Higgs boson mass in NUGM

we assume universal soft masses m_0 and A-term A_0 at the GUT scale

- top squark parameters

$$m_{\tilde{t}_L}^2(m_Z) \simeq +0.38M_2^2 + 5.63M_3^2 + 0.58m_0^2$$

$$m_{\tilde{t}_R}^2(m_Z) \simeq -0.21M_2^2 + 4.61M_3^2 + 0.19m_0^2$$

GUT scale

$$A_t(m_Z) \simeq -0.21M_2 - 1.90M_3 + 0.18A_0$$

- universal gaugino masses

$$M_{stop} \equiv \sqrt{m_{\tilde{t}_R} m_{\tilde{t}_L}}$$

$$M_2 = M_3 \gg m_0 \rightarrow \frac{A_t}{M_{stop}} \simeq \frac{2.11^2 \times M_3^2}{\sqrt{6.01 \cdot 4.40} \times M_3^2} \simeq 0.87$$

✓ 126 GeV Higgs boson requires heavy top squark $\gtrsim$ sub TeV

Higgs boson mass in NUGM

☐ top squark parameters

$$m_{\tilde{t}_L}^2(m_Z) \simeq +0.38M_2^2 + 5.63M_3^2 + 0.58m_0^2$$

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GUT scale

$$A_t(m_Z) \simeq -0.21M_2 - 1.90M_3 + 0.18A_0$$

☐ Non-Universal Gaugino Masses (NUGM)

- ✓ $m_{\tilde{t}_R}(m_Z)$ **decreases,** $|A_t(m_Z)|$ **increases as** M_2 **increases**

$$\rightarrow \quad A_t/M_{stop} \lesssim \sqrt{6}$$

- ✓ **upper bound is** $M_2/M_3 \lesssim 5$ **for** $m_{\tilde{t}_R}^2(m_Z) > 0$

- ✓ **In other words,** A_t/M_{stop} **is maximized at** $M_2/M_3 \sim 5$

brief summary

- ✓ large wino mass enhances the Higgs boson mass
- ✓ A_t/M_{stop} is maximized at $M_2/M_3 \simeq 5$

What happen for naturalness ?

naturalness in NUGM

- RG-running of m_{H_u}

$$m_{h_u}^2(m_Z) \simeq +0.17M_2^2 - 0.20M_2M_3 - 3.09M_3^2 - 0.23m_0^2$$ GUT scale

$$\rightarrow \quad M_2 \simeq 5 \times M_3 \ \rightarrow \ m_{h_u}^2(m_Z) \simeq 0$$

- ✓ μ-parameter is minimized at $M_2/M_3 \simeq 5$
- ✓ Higgs mass is also maximized at $M_2/M_3 \simeq 5$!

suitably large wino reconcile the Higgs mass and naturalness

our tuning measure

- our tuning measure (BG-type)

$$\Delta_\mu \equiv \left| \frac{d \ln m_Z^2}{d \ln \mu(\Lambda_{GUT})^2} \right|$$

- minimization condition of the Higgs potential

$$m_Z^2 \simeq -2\,|\mu|^2 + 2|m_{h_u}^2|$$

SUSY ~~SUSY~~

- ✓ we focus on tuning between μ-parameter and SUSY breaking parameters
- ✓ μ-parameter is unique SUSY dimensionful parameter in MSSM
- ✓ we expect some relations (e.g. gaugino mass ratio) among SUSY breaking parameters since these have same origin i.e. SUSY breaking mediation

NUGM from SUSY breaking mediation

☐ possibilities of NUGM (large wino)

- mixed moduli/anomaly mediation (mirage mediation)

$$M_a = \frac{F^T}{T+\bar{T}} + \frac{g_0^2}{16\pi^2} b_a \frac{F^C}{C} \qquad \text{where,} \quad b_a = \left(\frac{33}{5}, 1, -3\right)$$

$$a = U(1)_Y, SU(2)_L, SU(3)_C$$

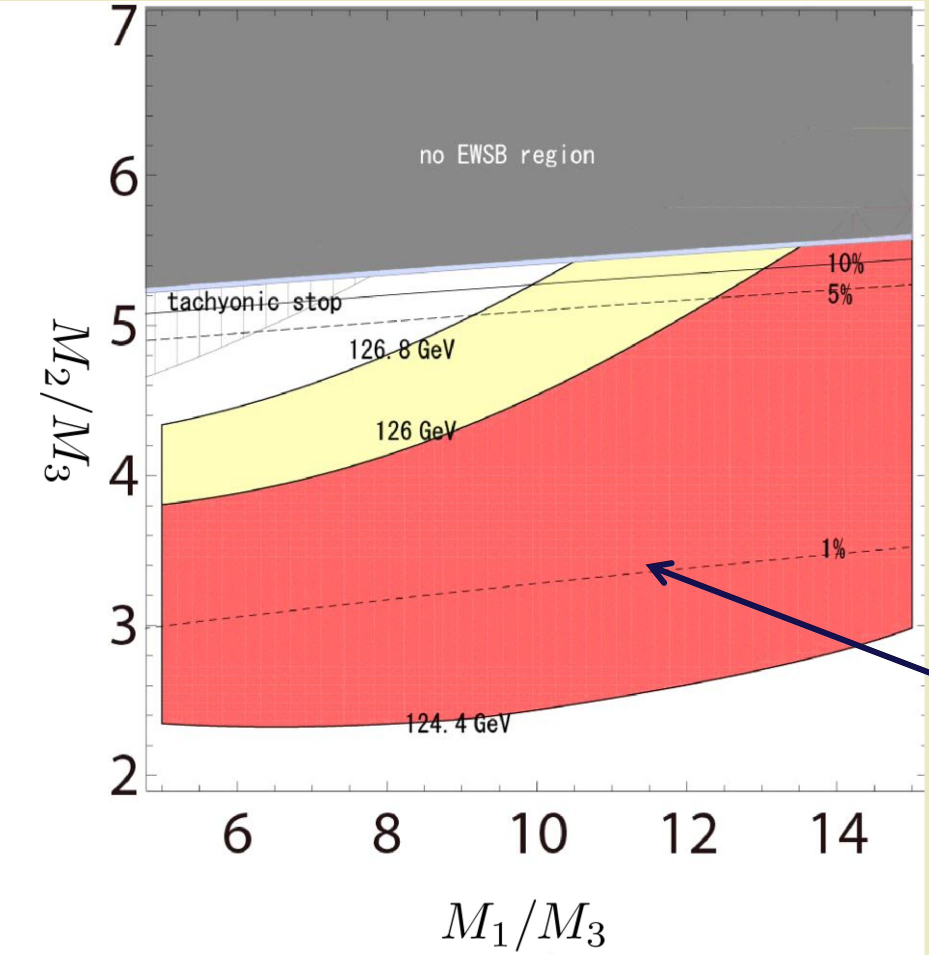
- moduli-mixing gauge kinetic function

$$\mathcal{L} \ni \int d^2\theta\, f_a(T) W^a W^a \ni f_a(T)\, F^{a\mu\nu} F^a_{\mu\nu}$$

$$f_a(T) = k_a^i\, T_i \quad \rightarrow \quad M_a = k_a^i \frac{F^{T_i}}{T_i + \bar{T}_{\bar{i}}}$$

Higgs boson mass in NUGM

- the Higgs boson mass and degree of tuning



$M_3 = 385\text{GeV}$

$A_0 = -400\text{GeV}$

$(m_0)_{3\text{rd}} = 200\text{GeV}$

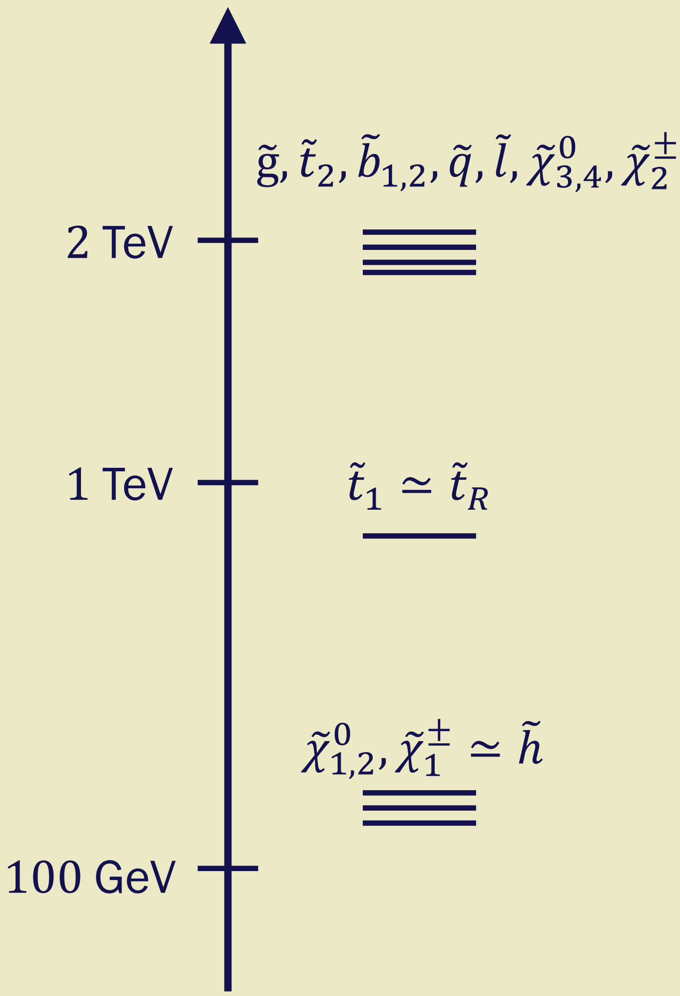
degree of tuning $100 \times |\Delta_\mu^{-1}|\%$

brief summary

- ✓ large wino mass enhances the Higgs boson mass
- ✓ A_t/M_{stop} is maximized at $M_2/M_3 \simeq 5$
- ✓ μ-parameter is also minimized at $M_2/M_3 \simeq 5$
- ✓ Higgs mass can reach 126 GeV even when $\Delta_\mu \lesssim 10$

How to probe NUGM ?

typical mass spectrum



✓ **most of sparticles are heavy**

- **these are determined by gluino mass** M_3

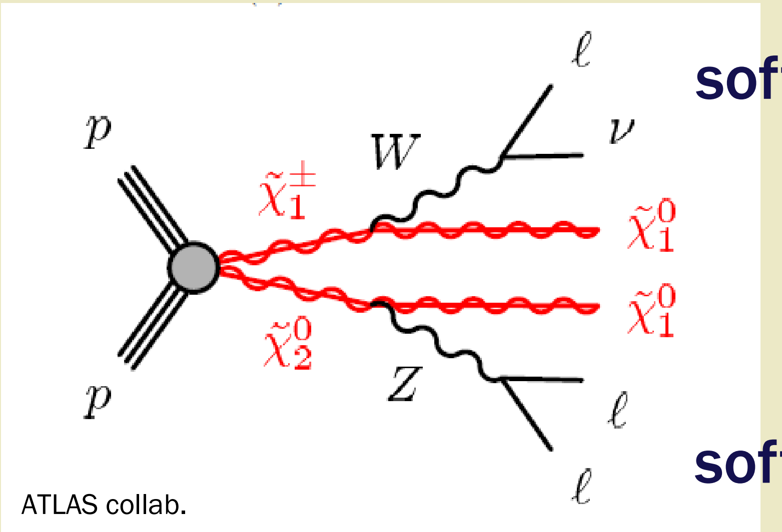
✓ **right-handed stop can be lighter than others**

- **as a result of large wino mass**

✓ **higgsinos are light**

decays of higgsinos

- higgsinos are light and degenerate $\Delta m_{\tilde{\chi}} \lesssim 2.0$ GeV



soft

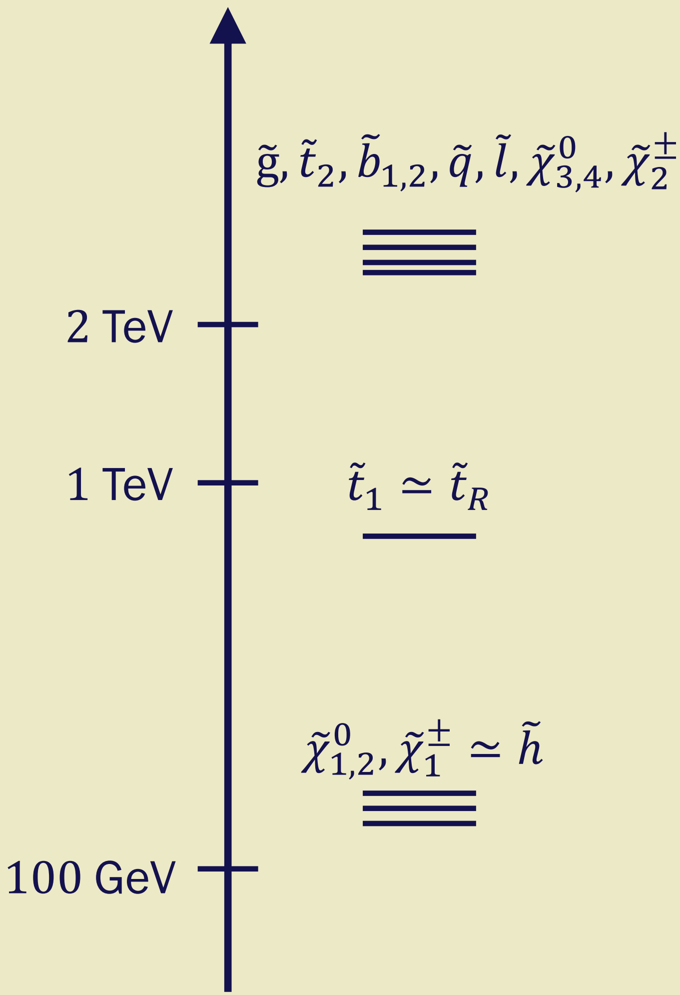
invisible

soft

- decay products are too soft to be reconstructed
- no charged tracks unlike pure wino

higgsino searches are not efficient

typical mass spectrum



✓ most of sparticles are heavy

- these are determined by gluino mass M_3

✓ right-handed stop is lighter than others

- as a result of large wino mass

✓ higgsinos are light, but degenerate

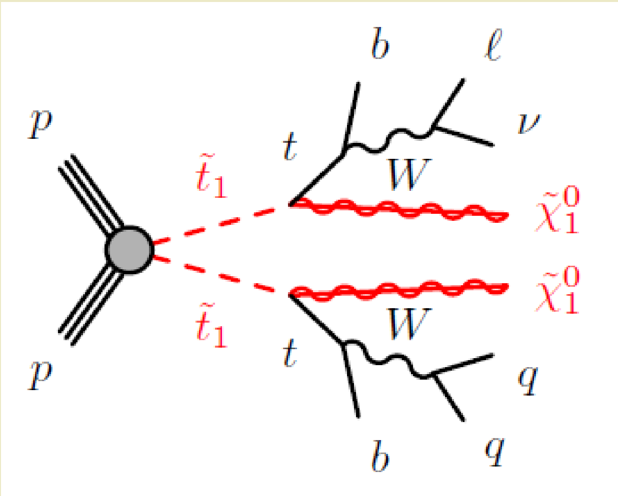
stop / gluino searches are important

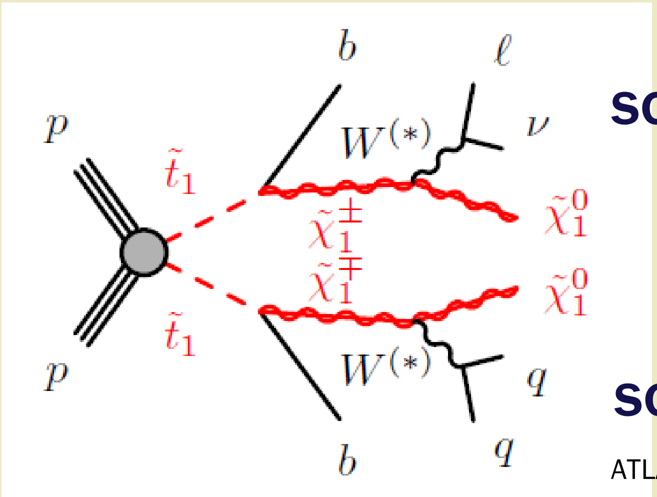
top squark decays

- right-handed top squark is light in NUGM

$$W_{MSSM} \ni y_t(t_L\, \tilde{h}_u^0 - b_L\, \tilde{h}_u^+)\, \tilde{t}_R$$

- top squark decays to $t + \tilde{\chi}_{1,2}^0$ or $b + \tilde{\chi}_1^\pm$
- right-handed top squark couples to quark/higgsinos universally
- $\mathrm{Br}(\tilde{t}_1 \to b\, \tilde{\chi}_1^\pm) = 1 - \mathrm{Br}(\tilde{t}_1 \to t\, \tilde{\chi}_{1,2}^0) \simeq 0.5$ unless $m_{\tilde{t}_1} \simeq m_{\tilde{\chi}_1}^\pm$





soft

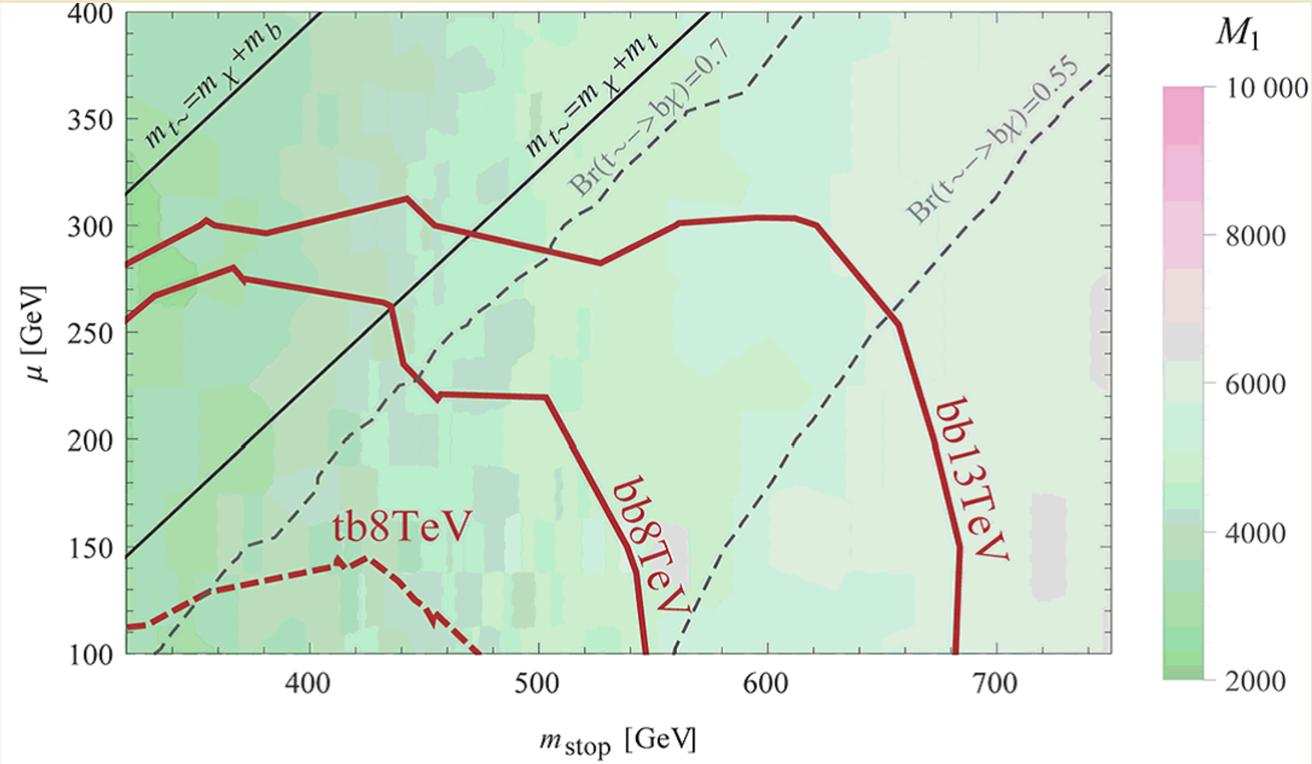
soft

ATLAS collab.

top squark search

- ✓ signals are tt (25%) / tb (50%) / bb (25%) + MET
- ✓ bb+MET channel gives the severer bound than tt+MET in run-1 result [1]
- ✓ 13TeV data[2] has already given the severest bound

$\tan\beta = 15$
$m_0 = 1$ TeV
$M_3 = 1$ TeV
$m_h = 125.8 \pm 0.3$ GeV
M_2, A_t: tuned

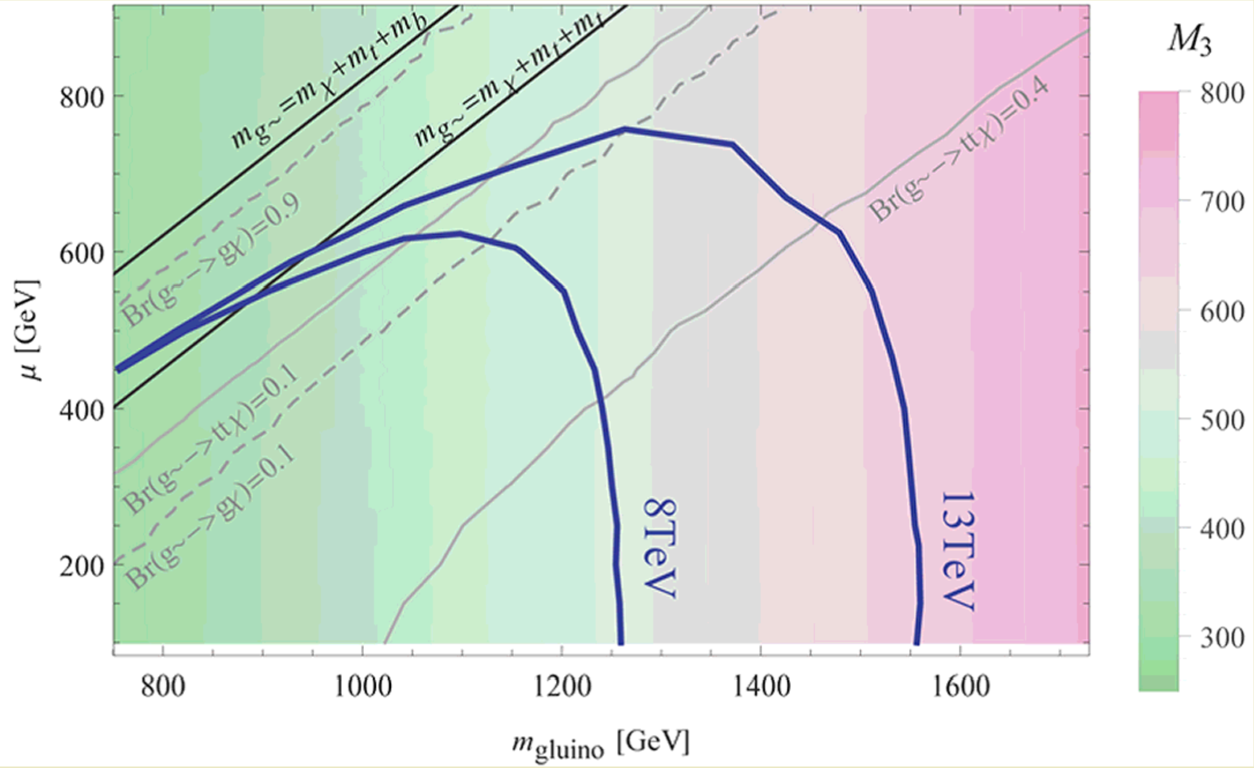


[1] ATLAS collab., JHEP **1310**, 189 (2013), Eur.Phys.J.C 75, no.10, 510 (2015)
[2] TLAS-CONF-2015-066

gluino search

- ✓ gluino decays to top and stop: $\tilde{g} \to t\,\tilde{t}_1 \to t + t\tilde{\chi}^0_{1,2}/b\,\tilde{\chi}^\pm_1$
- ✓ signals are characterized by 4 bottoms and large MET
- ✓ 13TeV data [3] has already given the severest bound

$\tan\beta = 15$
$m_0 = 1$ TeV
$M_1 = 12$ TeV
$m_h = 125.8 \pm 0.3$ GeV
M_2, A_t: tuned



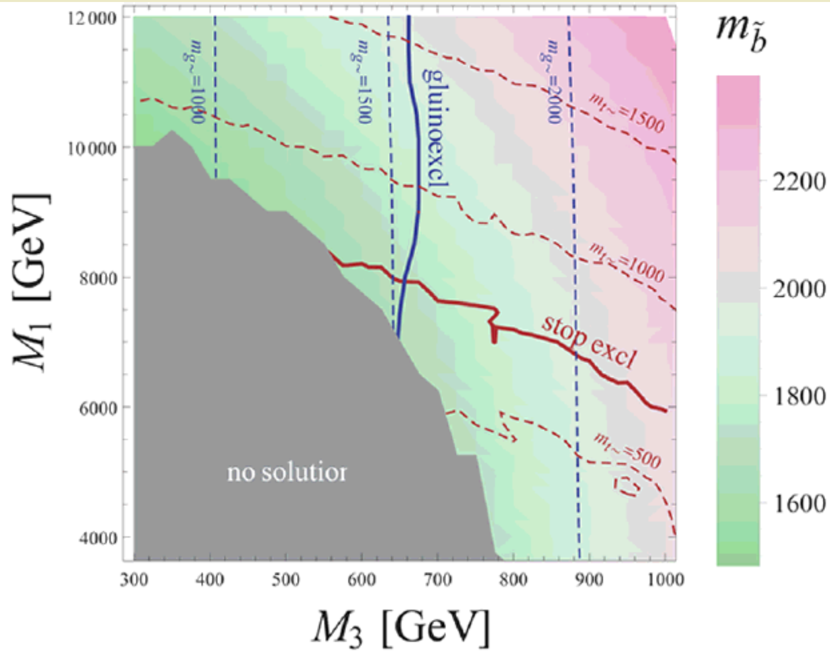
[3] ATLAS-CONF-2015-067

bounds on boundary conditions

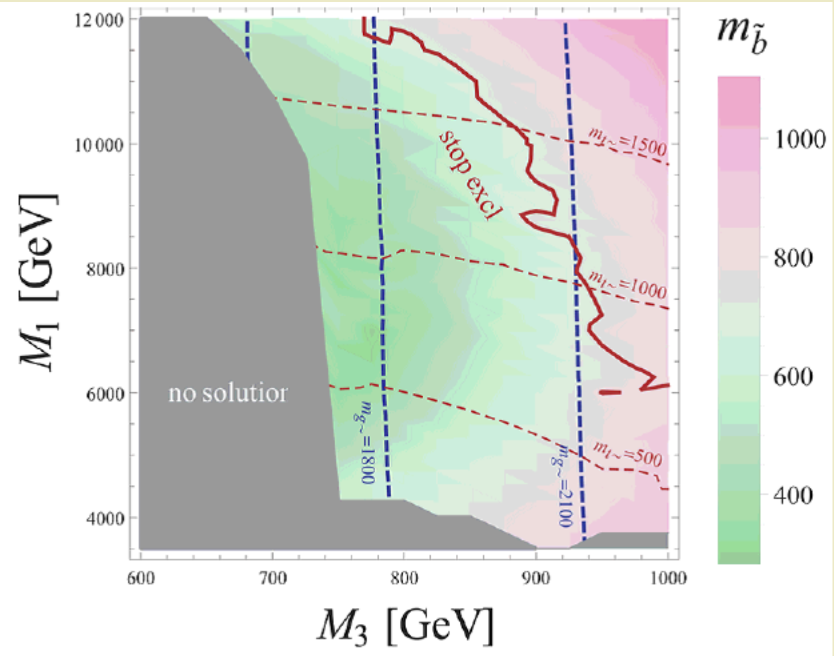
- ✓ right-handed sbottom can also be light for large $\tan\beta$
- ✓ sbottom pair production gives same signal as stop
- ✓ stop tends to be tachyonic for small M_1 and M_3

$m_0 = 1$ TeV
$\mu = 150$ GeV
$m_h = 125.8 \pm 0.3$ GeV
M_2, A_t: tuned

$\tan\beta = 15$



$\tan\beta = 50$



conclusion

- NUGM can realize 126GeV Higgs and small μ-parameter
- right-handed top squark tends to be light
- stop/gluino search are important for NUGM scenario
- $m_{\tilde{t}_1} \lesssim 700$ GeV, $m_{\tilde{g}} \lesssim 1.6$ TeV is excluded by the latest data

thank you for your attention

backups

degenerate higgsinos

- higgsinos are light and degenerate

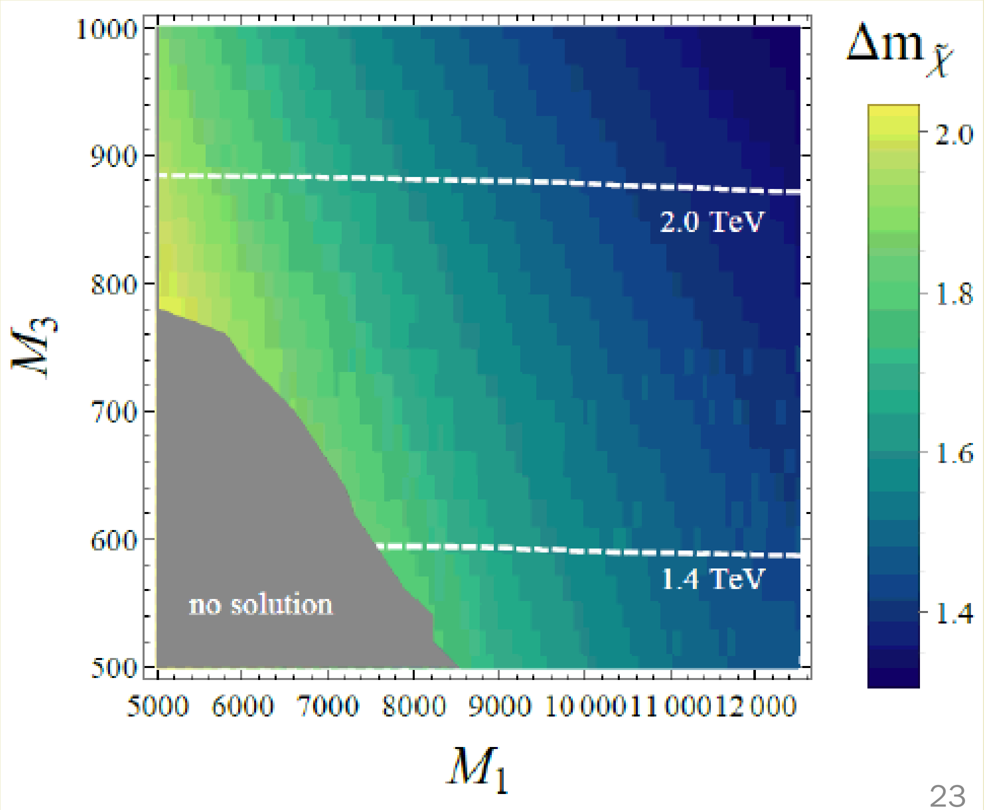
$m_0 = 1$ TeV
$\tan\beta = 15$
$\mu = 150$ GeV
M_2, A_t: tuned

heavy bino, wino $M_{1,2} \gg \mu$ leads $\Delta \mathrm{m}_{\tilde{\chi}} = O(1GeV)$

$$\Delta m_{\tilde{\chi}} \equiv m_{\tilde{\chi}_1^{\pm}} - m_{\tilde{\chi}_1^0} \simeq \frac{m_Z^2}{M_2(m_Z)}$$

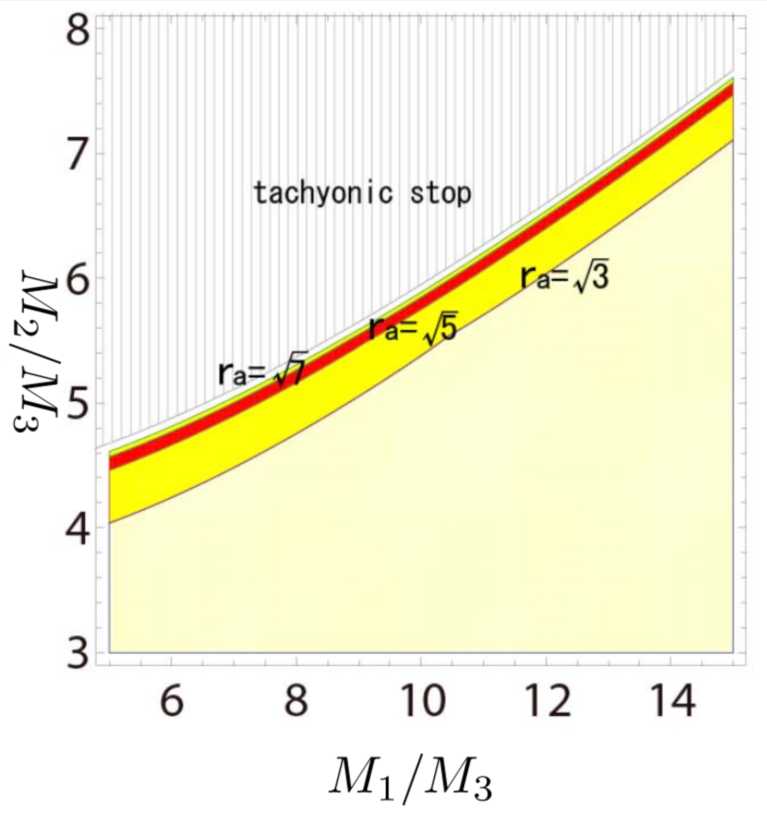
$M_{1,2} \simeq 2 - 4$ TeV

→ $\Delta \mathrm{m}_{\tilde{\chi}} \lesssim 2.0$ GeV



Higgs boson mass in NUGM

$r_a \equiv A_t/M_{st}$



$M_3 = 385\text{GeV}$

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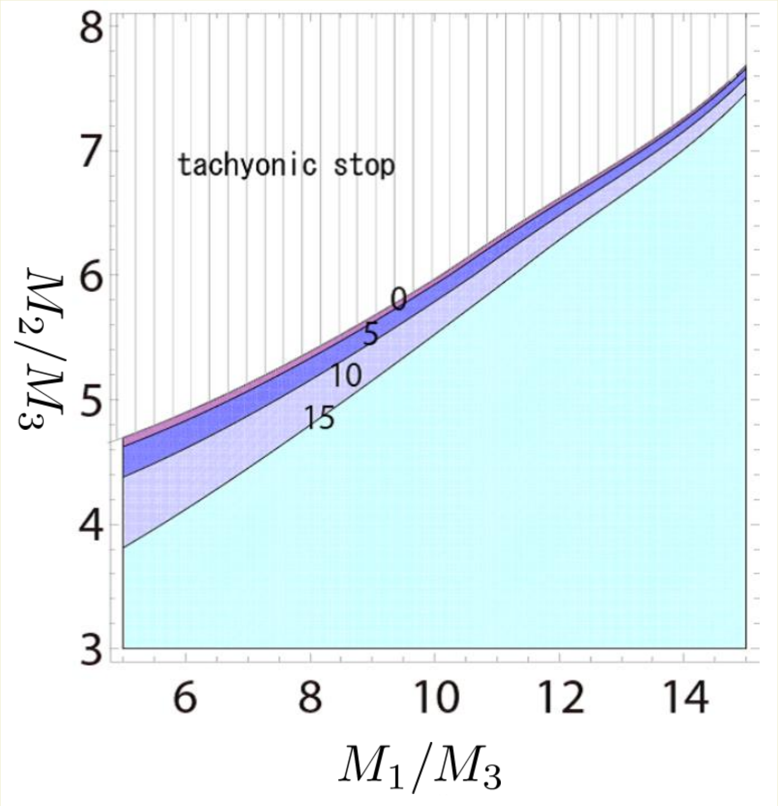
$(m_0)_{3\text{rd}} = 200\text{GeV}$

$M_{stop}/m_{\tilde{t}_L}$



$M_{stop} \equiv \sqrt{m_{\tilde{t}_R} m_{\tilde{t}_L}}$