SUSY at the LHC
in presence of 126GeV Higgs

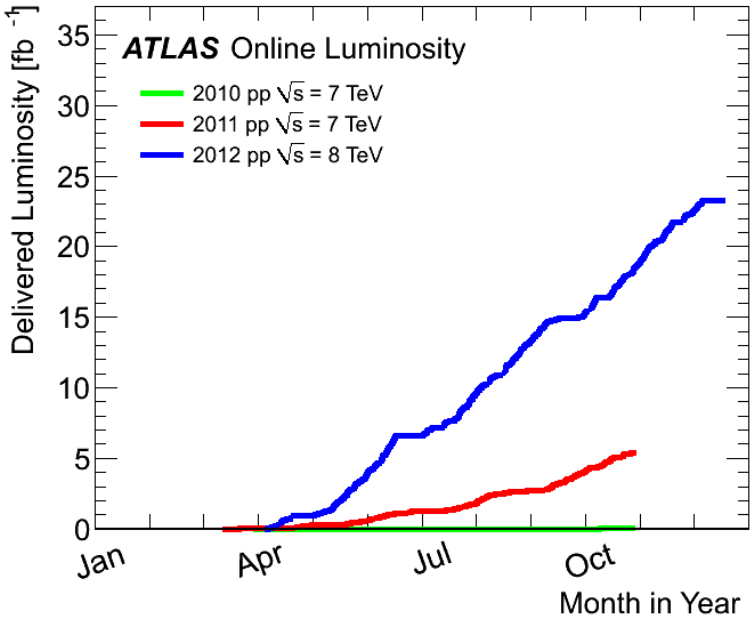
Sho IWAMOTO（岩本　祥）
The University of Tokyo, JAPAN　　(4月から Kavli IPMU に移籍)

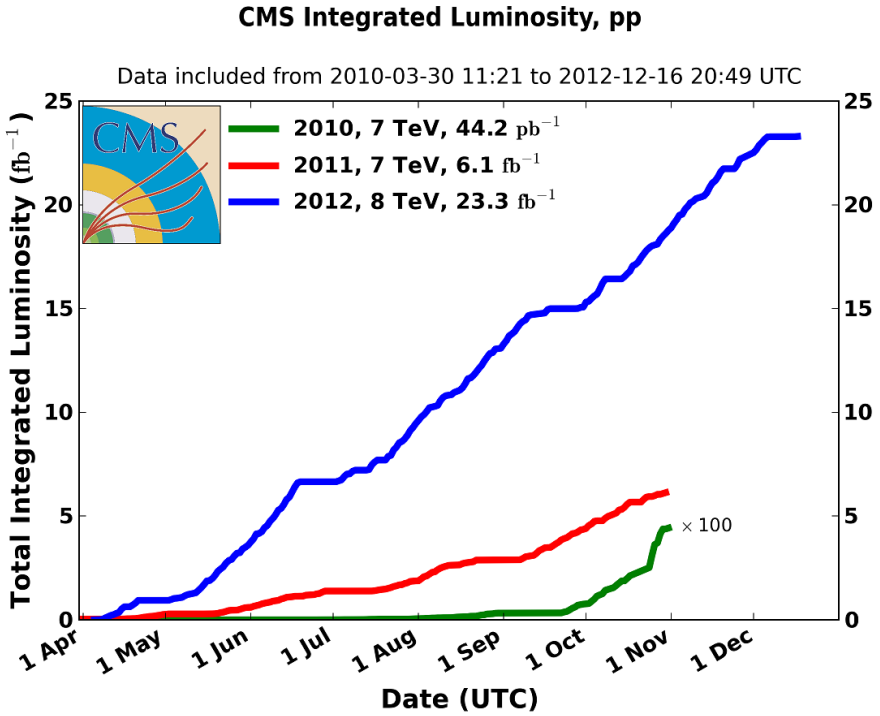
8th Feb. 2013
Seminar at Kyushu University

References)
Endo, Hamaguchi, SI, Yokozaki: [1108.3071][1112.5653][1202.2751],
Endo, Hamaguchi, Ishikawa, SI, Yokozaki: [1212.3935].

2012

LHC!!





ATLAS Recorded:

2012: 21.7 fb^{-1} @8TeV

2011: 5.25 fb^{-1} @7TeV

CMS Recorded:

2012: 21.8 fb^{-1} @8TeV

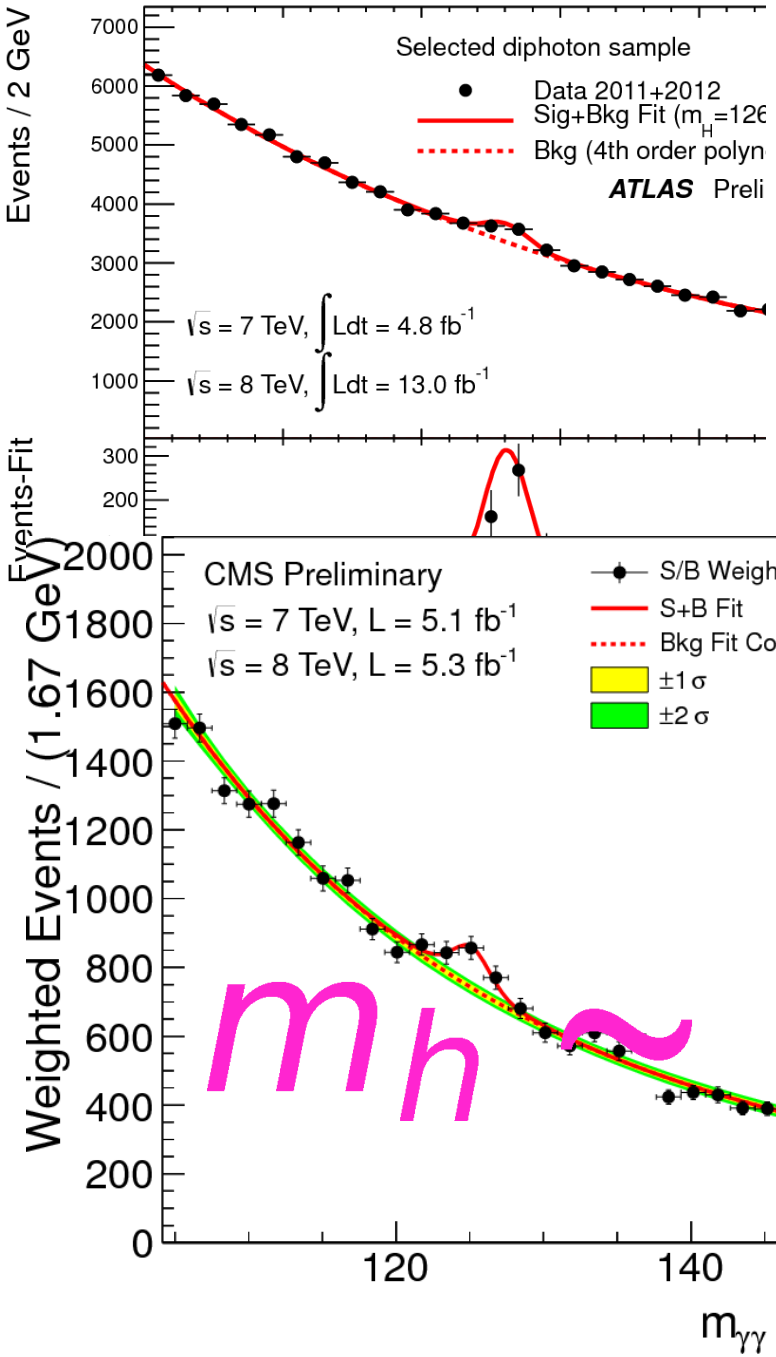
2011: 5.55 fb^{-1} @7TeV

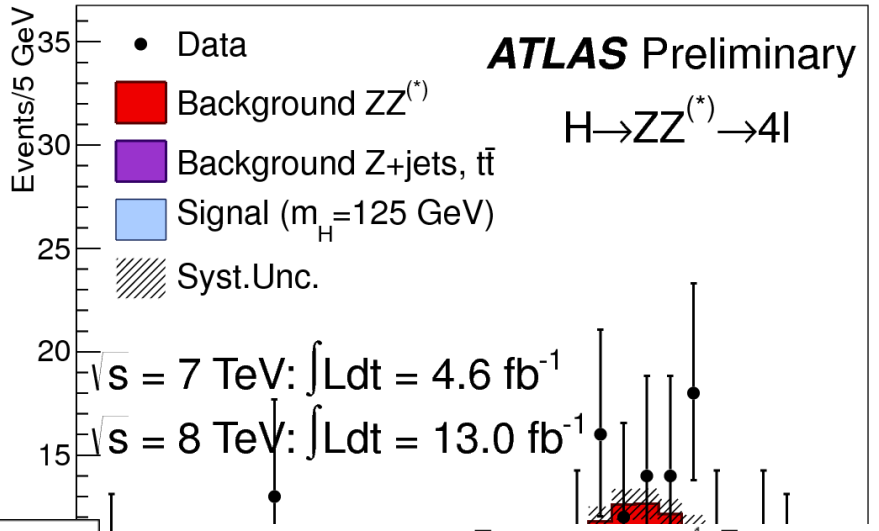
From ATLAS/CMS web

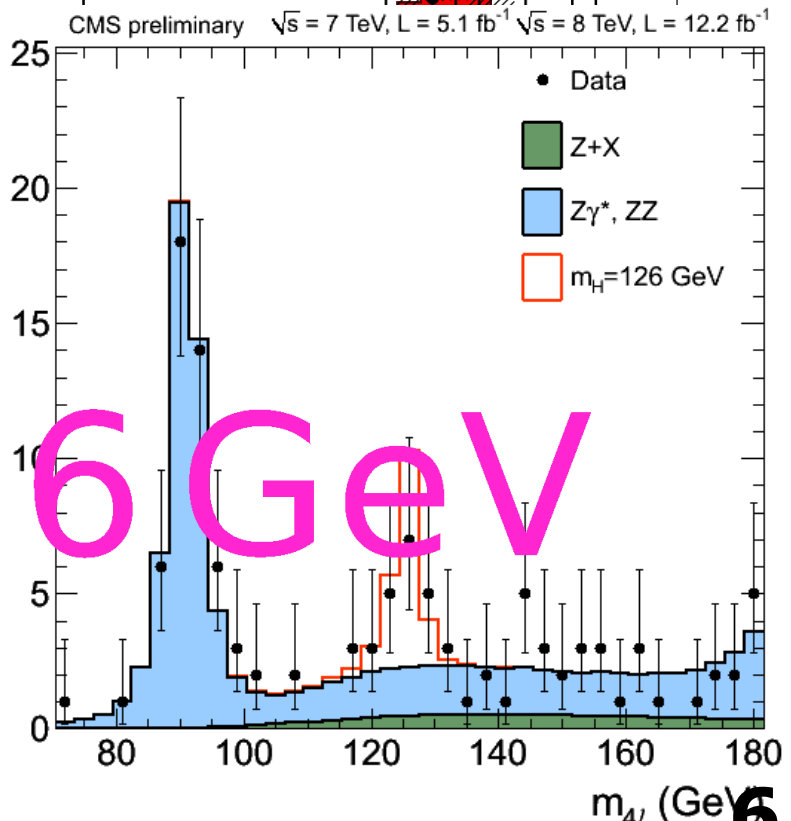
5,000,000,000,000,000（5×10^{15}=5000兆) pp collision in total!

(peak: 3.7nb^{-1}/s ~ 3.7×10^{9} coll./s)

Higgs boson was Discovered!







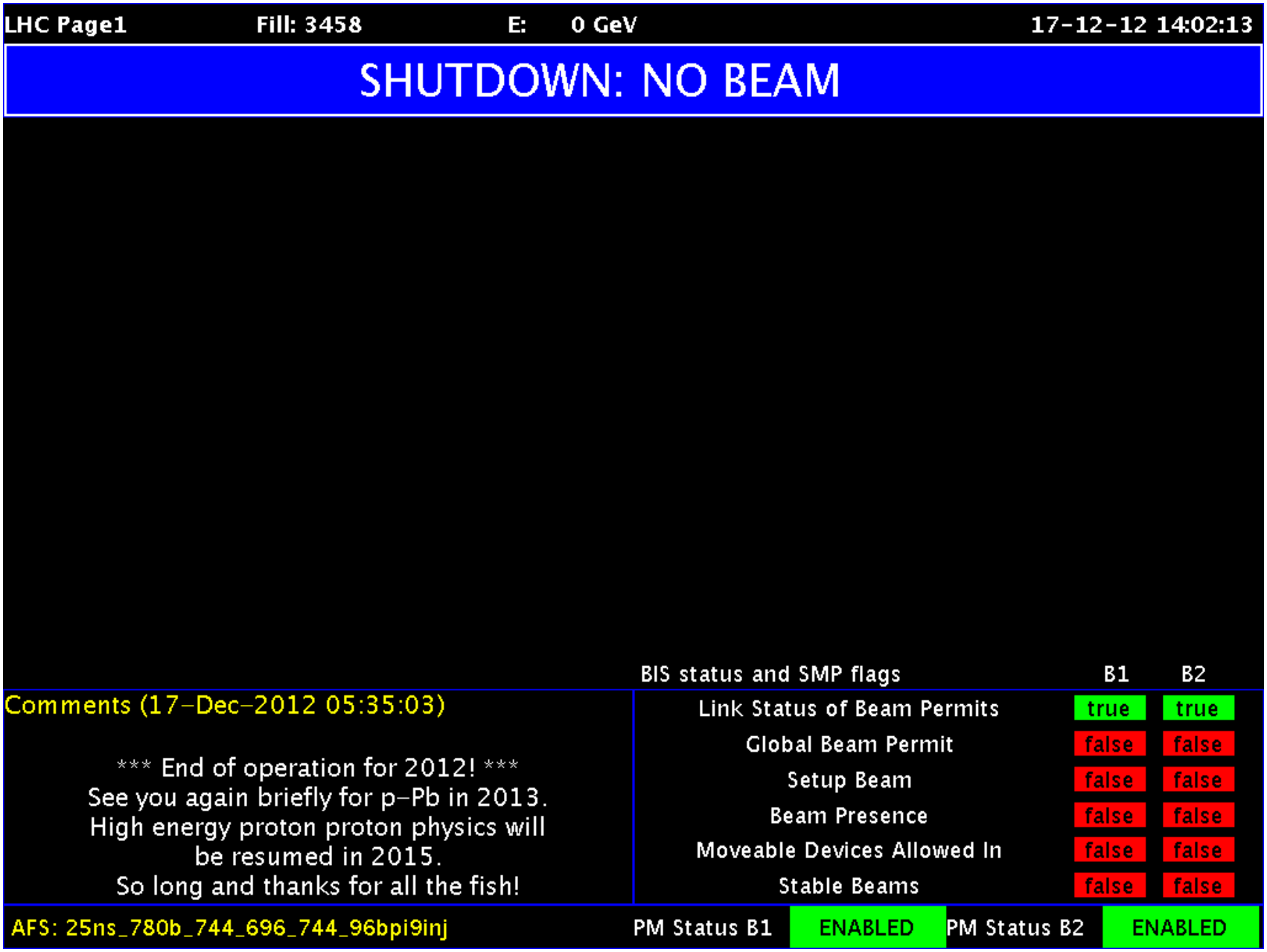
$m_h \approx 126$ GeV

but

SUSY Not Found.

Where's SUSY?

LHC
shut down.


LHC Page1
Fill: 3458
E: 0 GeV
17-12-12 14:02:13
SHUTDOWN: NO BEAM
BIS status and SMP flags
B1
B2
Comments (17-Dec-2012 05:35:03)
*** End of operation for 2012! ***
See you again briefly for p-Pb in 2013.
High energy proton proton physics will
be resumed in 2015.
So long and thanks for all the fish!
Link Status of Beam Permits
true
true
Global Beam Permit
false
false
Setup Beam
false
false
Beam Presence
false
false
Moveable Devices Allowed In
false
false
Stable Beams
false
false
AFS: 25ns_780b_744_696_744_96bpi9inj
PM Status B1
ENABLED
PM Status B2
ENABLED

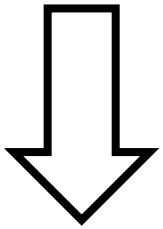
2015
2016 — 13TeV run, 100~200fb^{-1}?
2017
2018 — Long shut down (LS2)
2019
2020 — 13-14TeV run, 500fb^{-1}?
2021
2022
2023 — HL-LHC Installation? (proposal)
2024 — (finally 3000fb^{-1} @ 14TeV?)

1. **SUSY の現状 （126GeV Higgs を踏まえて）**
   - なぜ SUSY？
   - SUSY はどこにある？ ー Higgs, Naturalness, muon $g-2$
2. **MSSM + vectorlike model (V-MSSM)**
   - 模型の紹介
   - LHC からの制限
3. **Summary?**

SUSY の現状 (126 GeV Higgs を踏まえて)

標準模型 ようやく完成！？

- 階層性問題
- 暗黒物質の問題
- muon $g-2$：実験値とのずれ



Supersymmetry (SUSY)

SUSY

超対称性

Boson		Fermion
$\tilde{q}$	$\Leftrightarrow$	q
γ, Z, H_u^0, H_d^0	$\Leftrightarrow$	$\tilde{\chi}_{1-4}^0$
$\tilde{\mu}, \tilde{\nu}_\mu$	$\Leftrightarrow$	μ, ν_μ

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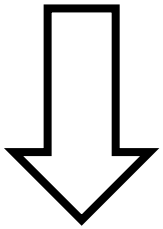


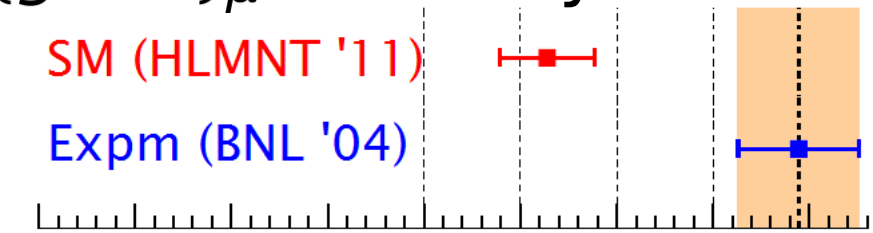
Supersymmetry (SUSY)

MSSM (Minimal SUSY Standard Model)

- 階層性問題 解決！
- 暗黒物質 候補あり！
- muon $g-2$ 説明できる！ 

$\left(a_\mu := \frac{g_\mu - 2}{2}\right)$

$(g-2)_\mu$ anomaly



$a_\mu^{\rm SM} = (116\,591\,828 \pm 49) \times 10^{-11}$

$a_\mu^{\rm exp} = (116\,592\,089 \pm 63) \times 10^{-11}$

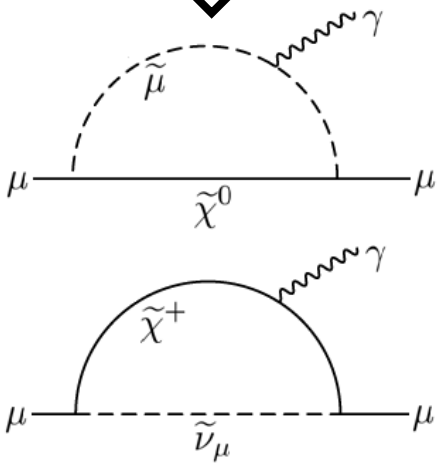
Hagiwara, Liao, Martin, Nomura, Teubner [1105.3149]

3.3σ discrepancy

Can be explained with SUSY

if $\mu > 0$, $\tan\beta \gtrsim 10$,

and $m\left(\tilde{\chi}^0, \tilde{\chi}^\pm, \tilde{\mu}, \tilde{\nu}_\mu\right) \sim {\rm O}(100)\,{\rm GeV}$.



$$\Delta a_\mu\left(\tilde{\chi}^0, \tilde{\mu}\right) \approx \frac{\alpha_Y m_\mu^2}{m_{\rm soft}^2} {\rm sgn}(\mu M_1) \tan\beta + \cdots,$$

$$\Delta a_\mu\left(\tilde{\chi}^\pm, \tilde{\nu}\right) \approx \frac{\alpha_2 m_\mu^2}{m_{\rm soft}^2} {\rm sgn}(\mu M_2) \tan\beta.$$

$\left(\tan\beta = \frac{\langle H_u \rangle}{\langle H_d \rangle}\right)$

Moroi [ph/9512396]

Cho, Hagiwara, Matsumoto, Nomura [1104.1769]

標準模型 ようやく完成！？

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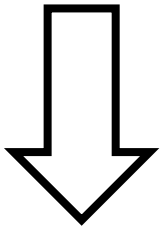

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↳ $m\left(\tilde{\chi}^0, \tilde{\chi}^{\pm}, \tilde{\mu}, \tilde{\nu}_{\mu}\right) \sim \mathrm{O}(100)\,\mathrm{GeV}$

and large $\tan\beta$??

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  and large $\tan\beta$??

- $m_h = 126\,\mathrm{GeV} \Longrightarrow$
- Little hierarchy の議論 $\Longrightarrow$
- まだ見つかってない $\Longrightarrow$

tree　　one-loop level (top-stop)

$$m_h^2 \approx m_Z^2 + \frac{3 g_W^2 m_t^4}{8\pi^2 m_W^2}\left[\ln\frac{m_{\tilde{t}}^2}{m_t^2} - \frac{(\alpha^2-6)^2}{12} + 3\right]$$

where $\alpha := A_t/m_{\tilde{t}}$.

(stop mixing parameter)

m_h が重い $\Longleftrightarrow$

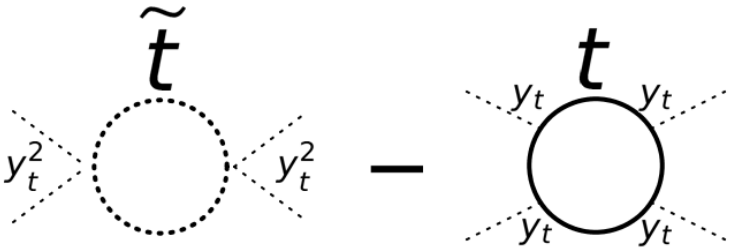
- $\tilde{t}$ がとても重い

  and/or

- $\tilde{t}$ の混合parameter α がちょうどいい $(\sim \pm\sqrt{6})$.

$$m_{\tilde{t}} \sim \begin{cases} 1\text{–}2\,\text{TeV} & (\alpha \sim \pm\sqrt{6}) \\ \text{maximal-mixing (“}m_h\text{-max”) scenario} & \\ \text{O(10) TeV} & (\alpha \sim 0) \\ \text{small mixing case} & \end{cases}$$

h^4 :



Okada, Yamaguchi, Yanagida, 1991
Ellis, Ridolfi, Zwirner, 1991
Haber, Hempfling, 1991

MSSM (Minimal SUSY Standard Model)

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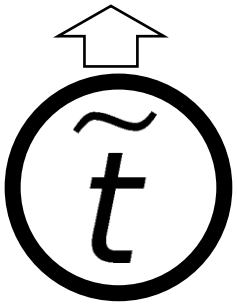
  and large $\tan\beta$??

- $m_h = 126\,\mathrm{GeV} \Longrightarrow m\left(\tilde{t}\right) \sim \mathrm{O}(1\text{–}10)\,\mathrm{TeV}$??
- Little hierarchy の議論 $\Longrightarrow$
- まだ見つかってない $\Longrightarrow$

- Higgs: $\langle h \rangle \approx 174\,\mathrm{GeV}$

$$\Rightarrow \underbrace{\frac{g^2 + g'^2}{2}\langle h \rangle^2}_{m_Z^2} \approx \underbrace{2\left(-m_{H_u}^2\right) - 2|\mu|^2}_{\text{cancellation}} + \mathrm{O}\left(\frac{1}{\tan\beta}\right)$$



$$\Delta m_{H_u}^2 \approx -\frac{3y_t^2}{4\pi^2} m_{\tilde{t}}^2 \log\frac{\Lambda}{m_{\tilde{t}}}$$

重い stop は
fine-tuneを
再び呼び覚ます！

まじめに計算すると……　$\tilde{t}$：600 GeV ⇒ 10% tuning

1.8 TeV ⇒ 1% tuning

MSSM (Minimal SUSY Standard Model)

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  and large $\tan\beta$??

- $m_h = 126\,\mathrm{GeV} \Longrightarrow m\left(\tilde{t}\right) \sim \mathrm{O}(1\text{–}10)\,\mathrm{TeV}$??
- Little hierarchy の議論 $\Longrightarrow m\left(\tilde{t}\right) \lesssim 1\,\mathrm{TeV}$??
- まだ見つかってない $\Longrightarrow$

Hard jets + Missing energy

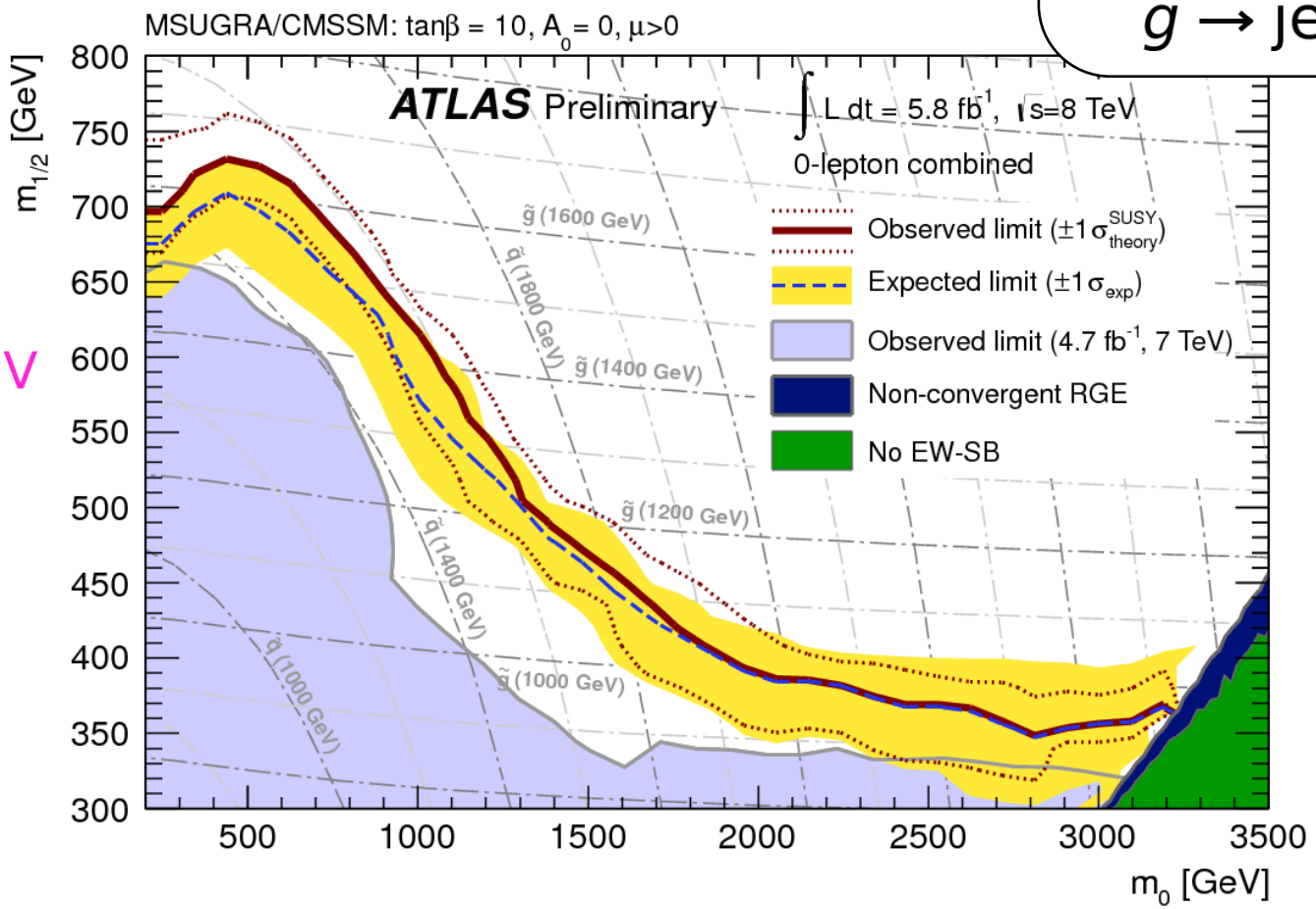
$pp \to \tilde{g}\tilde{g}$

$\tilde{g} \to \text{jets} + \text{LSP}$

$\tilde{g} \sim \tilde{q}$

$\Downarrow$

$> 1.5\,\text{TeV}$

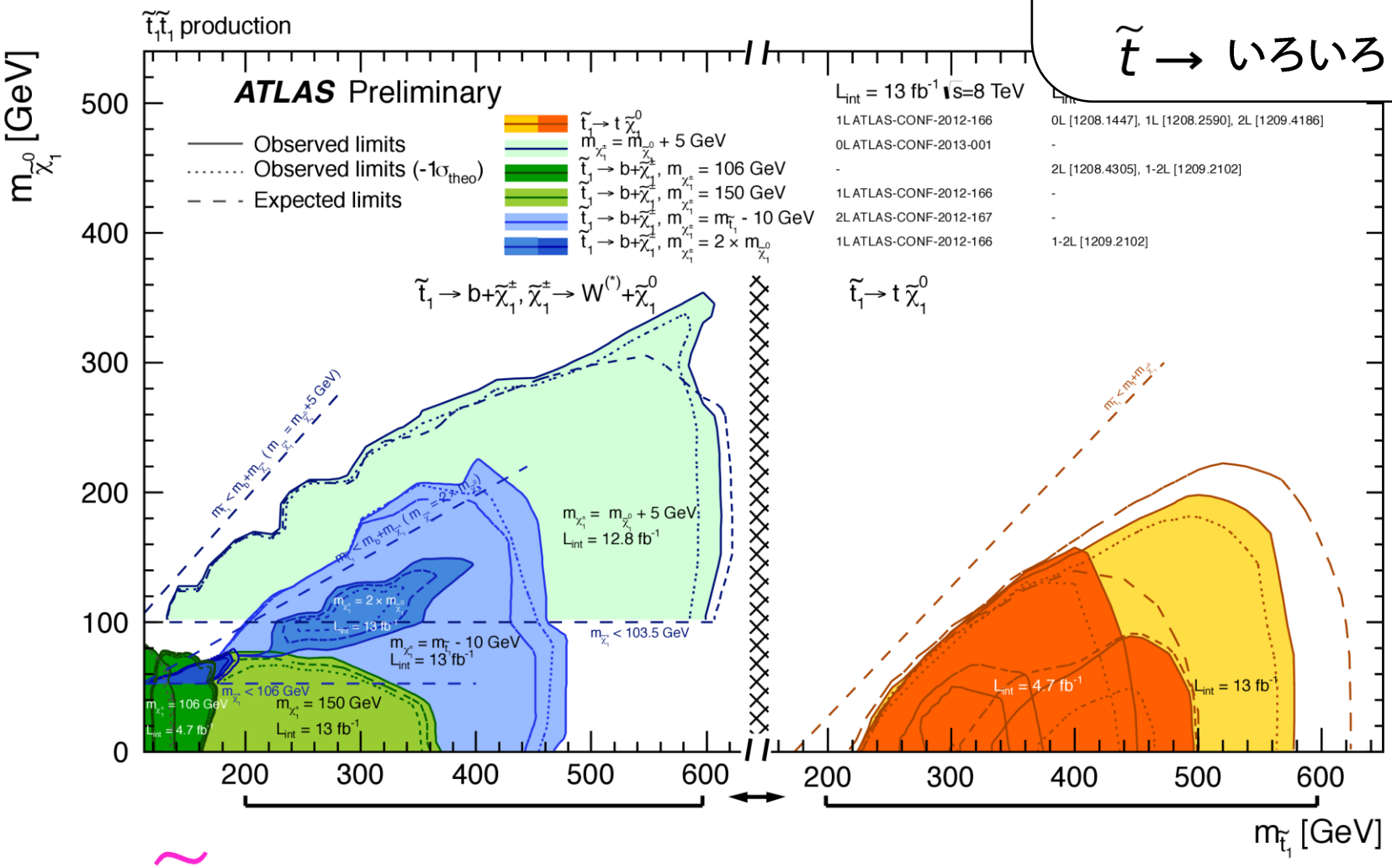


$\tilde{q}$: decoupled $\Rightarrow$ $\tilde{g} > 900\,\text{GeV}$

From [ATLAS SUSY public web page]

$pp \to \tilde{t}\tilde{t}^*$

$\tilde{t} \to$ いろいろ



$\tilde{t} \gtrsim 600$ GeV

（仮定：LSPと縮退していない&*R*-parity保存）

MSSM (Minimal SUSY Standard Model)

- 階層性問題 解決！
- 暗黒物質 候補あり！
- muon $g-2$ 説明できる！

  ↳ $m\left(\tilde{\chi}^0, \tilde{\chi}^{\pm}, \tilde{\mu}, \tilde{\nu}_{\mu}\right) \sim \mathrm{O}(100)\,\mathrm{GeV}$
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- $m_h = 126\,\mathrm{GeV} \Longrightarrow m\left(\tilde{t}\right) \sim \mathrm{O}(1\text{–}10)\,\mathrm{TeV}$??
- Little hierarchy の議論 $\Longrightarrow m\left(\tilde{t}\right) \lesssim 1\,\mathrm{TeV}$??
- まだ見つかってない $\Longrightarrow m\left(\tilde{t}\right) \gtrsim 600\,\mathrm{GeV}$
  $m(\tilde{g}, \tilde{q}) \gtrsim 1\,\mathrm{TeV}$

V-MSSM / V-GMSB

Vector-like matter

MSSM (Minimal SUSY Standard Model)

- muon $g-2$ のずれ $\Longrightarrow m\left(\tilde{\chi}^0, \tilde{\chi}^{\pm}, \tilde{\mu}, \tilde{\nu}_{\mu}\right) \sim \mathrm{O}(100)\,\mathrm{GeV}$ and large $\tan\beta$??
- $m_h = 126\,\mathrm{GeV} \Longrightarrow m\left(\tilde{t}\right) \sim \mathrm{O}(1\text{–}10)\,\mathrm{TeV}$??

$$m_{\tilde{t}} \sim \begin{cases} 1\text{–}2\,\mathrm{TeV} & [\alpha = A_t/m_{\tilde{t}} \sim \pm\sqrt{6} \ : \text{ maximal-mixing (“}m_h\text{-max”) scenario}] \\ \mathrm{O}(10)\,\mathrm{TeV} & [\text{small } \alpha \text{ (small mixing)}] \end{cases}$$

両立は可能か？ ⇨ 簡単なSUSY模型では難しい

例：GMSB や CMSSM(mSUGRA) では不可能

$m_{\tilde{q}} \Longleftrightarrow m_{\tilde{l}}$ & A_t cannot be large.

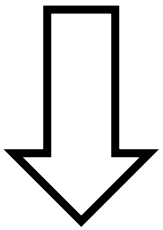
GUT → 相関

CMSSM → A_0 is constrained from $\mathrm{Br}(b \to s\gamma)$.
GMSB → $A_t = 0$ at one-loop level.

Endo, Hamaguchi, SI, Nakayama, Yokozaki [1112.6412]
Ghilencea, Lee, Park [1203.0569]

MSSM + GMSB (or mSUGRA)

$\Longrightarrow$ ~~$(g-2)_\mu$ with $m_h = 126$ GeV~~

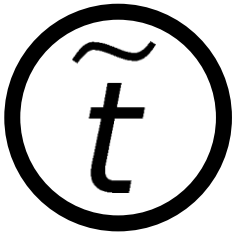


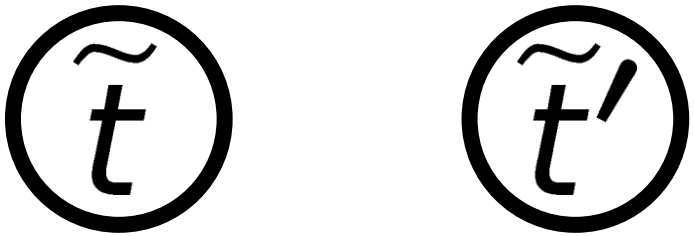
MSSM + **more complicated ~~SUSY~~**

or

V-MSSM + GMSB/mSUGRA

Key Idea

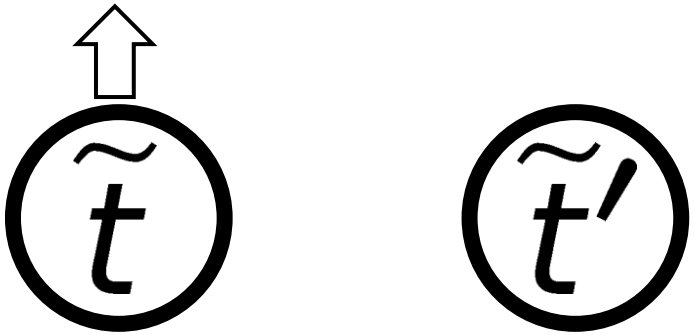




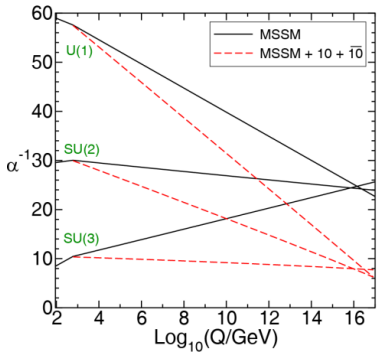
$(g-2)_\mu \cdots m\left(\tilde{\chi}^0, \tilde{\chi}^\pm, \tilde{\mu}, \tilde{\nu}_\mu\right) \sim \mathrm{O}(100)\,\mathrm{GeV}??$

Conflict resolved.

$m_h \sim 126\,\mathrm{GeV} \cdots$ ~~$m\left(\tilde{t}\right) \sim \mathrm{O}(1\text{–}10)\,\mathrm{TeV}??$~~ $\tilde{t}$ can be lighter.



- No gauge anomaly.
- Gauge couplings unification.



Martin [0910.2732]

◉ V-MSSM =

$$\mathrm{MSSM}+(\underbrace{\mathbf{10}+\overline{\mathbf{10}}}_{\text{extra Vector-like matters}}),\ \text{i.e.}\ \begin{cases}\mathbf{10}=(Q',\bar{U}',\bar{E}')\\ \overline{\mathbf{10}}=(\bar{Q}',U',E')\end{cases}$$

$$W_{\text{extra}}=Y'Q'H_u\bar{U}'+Y''\bar{Q}'H_dU' \qquad (\text{cf. } W_{\text{MSSM}}\ni Y_tQH_u\bar{U})$$
$$+M_VQ'\bar{Q}'+M_VU'\bar{U}'+M_VE'\bar{E}'$$

$$W_{\text{mix}}=\epsilon_iQ_iH_uU'+\epsilon'_iQ'H_u\bar{U}_i+\epsilon''_iQ'H_d\bar{D}_i+\epsilon^L_iL_iH_d\bar{E}'$$

Mixing between SM- & vector-like quark

- Too large → flavor problem.
- No mixing→ stable colored particle.

⇨ 十分小さいと仮定

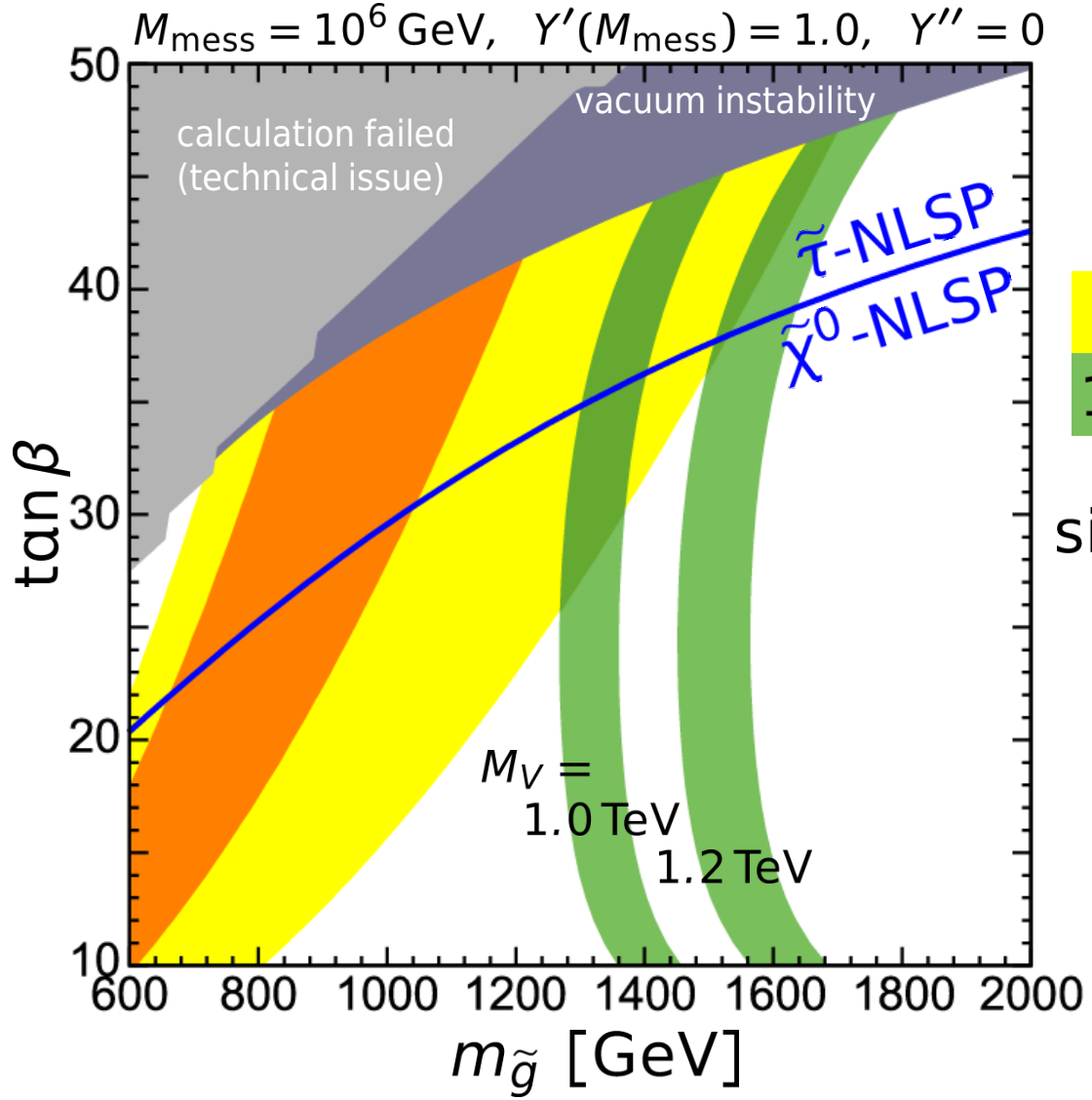
- Y’ : IR fixed point behavior to ~1.05 ⇨ m_h は自然に持ち上がる
- Y’’ : reduces m_h ⇨ 十分小さいと仮定

RESULT

with { GMSB framework
mSUGRA framework
（今回は省略）

params: $(\Lambda,\ M_{\rm mess},\ \tan\beta,\ N_{\rm mess},\ {\rm sgn}\,\mu;\ Y',\ M_V)$

$N_{\rm mess}$ = 1 + Δ(g-2)>0 ; Y' = 1.0 (IR fixed)



$g-2$ 1σ 2σ

$125\,{\rm GeV} < m_h < 126\,{\rm GeV}$

simultaneous realization:

$M_V \lesssim 1.2$ TeV,

$m_{\tilde{g}} \lesssim 1.6$ TeV,

$\tan\beta \sim {\rm O}(10)$

➡ **LHC LIMIT!?**

LHC constraints on V-MSSM

(1) from searches for extra quarks.

(2) from searches for SUSY.

LHC constraints on V-MSSM

(1) from searches for extra quarks.

(2) from searches for SUSY.

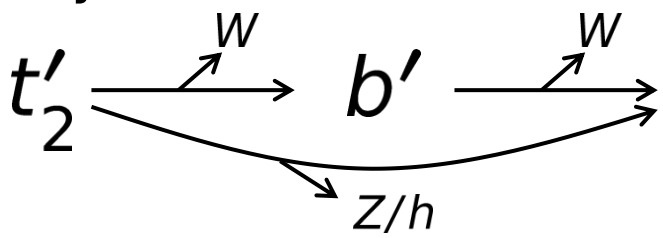
- $(Q', \bar{U}', \bar{E}') + (\bar{Q}', U', E') \to \left(\tilde{t}'_{1,2,3,4}, \tilde{b}'_{1,2}, \tilde{\tau}'_{1,2}\right)$
  $\& \left(t'_1, t'_2, b', \tau'\right)$

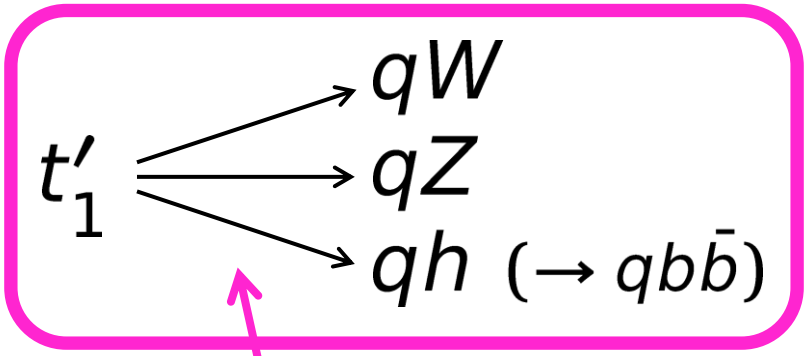
  - Mass
    $m_{t'} \sim M_V \pm (174\,\mathrm{GeV}/2)$,
    $m_{b'} = m_{\tau'} = M_V$

$$W_{\mathrm{extra}} = Y' Q' H_u \bar{U}' + M_V Q' \bar{Q}' + M_V U' \bar{U}' + M_V E' \bar{E}'$$
$$W_{\mathrm{mix}} = \epsilon_i Q_i H_u U' + \epsilon'_i Q' H_u \bar{U}_i + \epsilon''_i Q' H_d \bar{D}_i + \epsilon^L_i L_i H_d \bar{E}'$$

  - Production
    $pp \to t'_1 \bar{t}'_1$ etc. (pair production)

  - Decay





depending on mixing
btw. vec-like/SM quarks.

- $(Q', \bar{U}', \bar{E}') + (\bar{Q}', U', E') \to \left(\tilde{t}'_{1,2,3,4}, \tilde{b}'_{1,2}, \tilde{\tau}'_{1,2}\right)$ & $\left(t'_1, t'_2, b', \tau'\right)$

  - Current bounds

    $W_{\rm mix} = \epsilon_i Q_i H_u U' + \epsilon'_i Q' H_u \bar{U}_i + \epsilon''_i Q' H_d \bar{D}_i + \epsilon^L_i L_i H_d \bar{E}'$

    - Under "exclusive decay" assumption

3rd gen only (favored to avoid flavor constr.)

$t'_1 \to bW$ :: $m_{t'_1} > 656\,\text{GeV}$ ATLAS 7 TeV-4.7fb^{-1} [1210.5468]

$t'_1 \to tZ$ :: $m_{t'_1} > 625\,\text{GeV}$ CMS 7 TeV-5.0fb^{-1} [1210.7471]

$t'_1 \to th$ :: No bound yet

$t'_1 \to q_d W$ :: $m_{t'_1} > 350\,\text{GeV}$ ATLAS 7 TeV-1.04fb^{-1} [1202.3389]

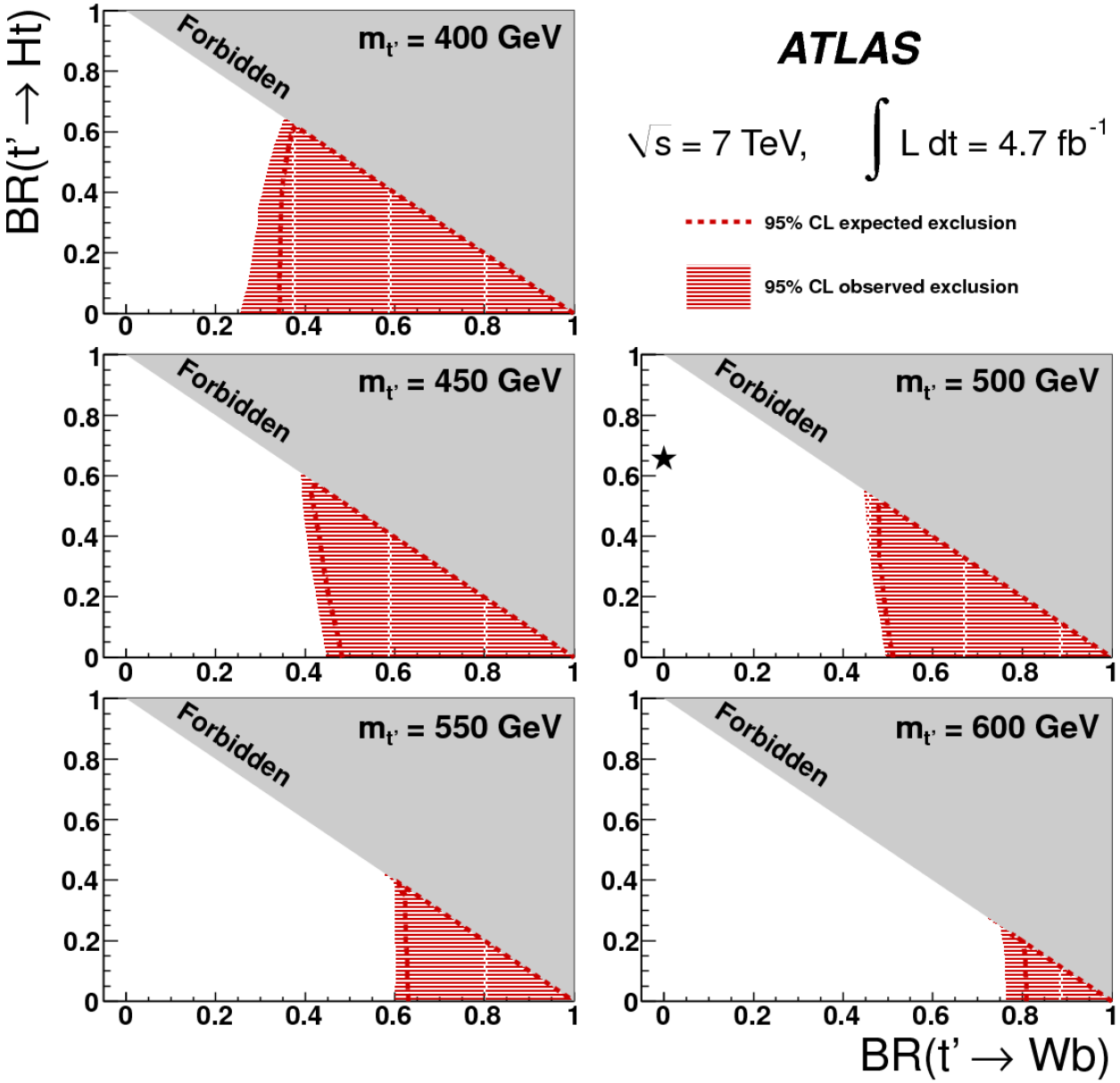
$t'_1 \to q_u Z$ :: No bound yet

$t'_1 \to q_u h$ :: No bound yet

$m_{t'_1} \sim M_V - 87\,\text{GeV}$,
$pp \to t'_1 \bar{t}'_1$, $t'_1 \to (qW, qZ, qh)$

- Generic analysis (3rd gen. assumption : $t'_1 \to (bW, tZ, th)$)
  - Done by ATLAS (7 TeV-4.7fb^{-1} [1210.5468])

$M_V \lesssim 750\,\text{GeV}$ cases have (some) constraints.



$t' \to Wb$ (x-axis)
Ht (y-axis)
Zt

$1l + 3j(1b) + \not{E}_T$

$t'\bar{t}' \to (Wb)(Wb)$
$\to (l\nu)(jj)bb$

LHC constraints on V-MSSM

(1) from searches for extra quarks.

(2) from searches for SUSY.

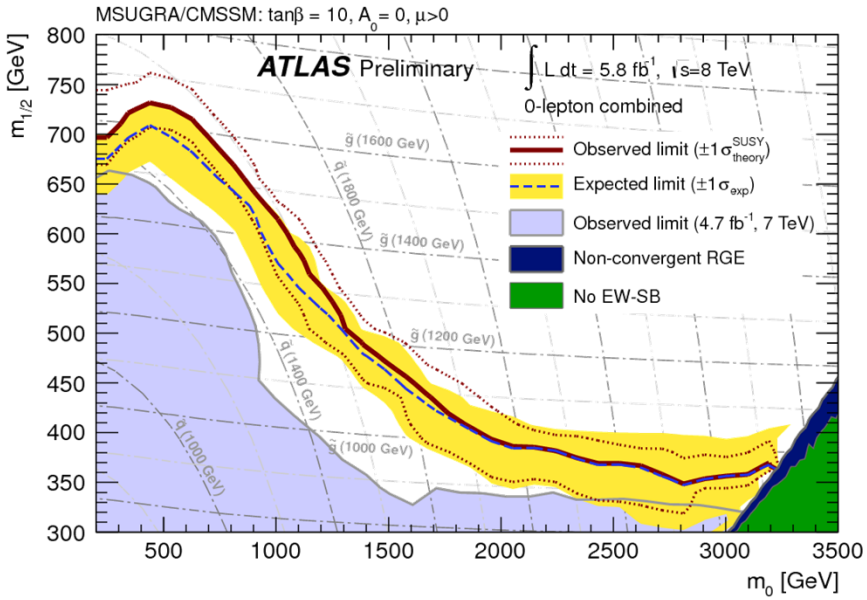
NLSP	Long-lived NLSP	NLSP prompt decay
$\tilde{\chi}_1^0$	jet + $\not{E}_T$ ($\tilde{\chi}_1^0\tilde{\chi}_1^0$) (same as mSUGRA)	jet + $\not{E}_T$ and $2\gamma + \not{E}_T$ (from $\tilde{\chi}_1^0 \rightarrow \gamma\tilde{G}$)
$\tilde{\tau}_1$	Long-lived stau	multi-tau

Examined

⇩ left as future works

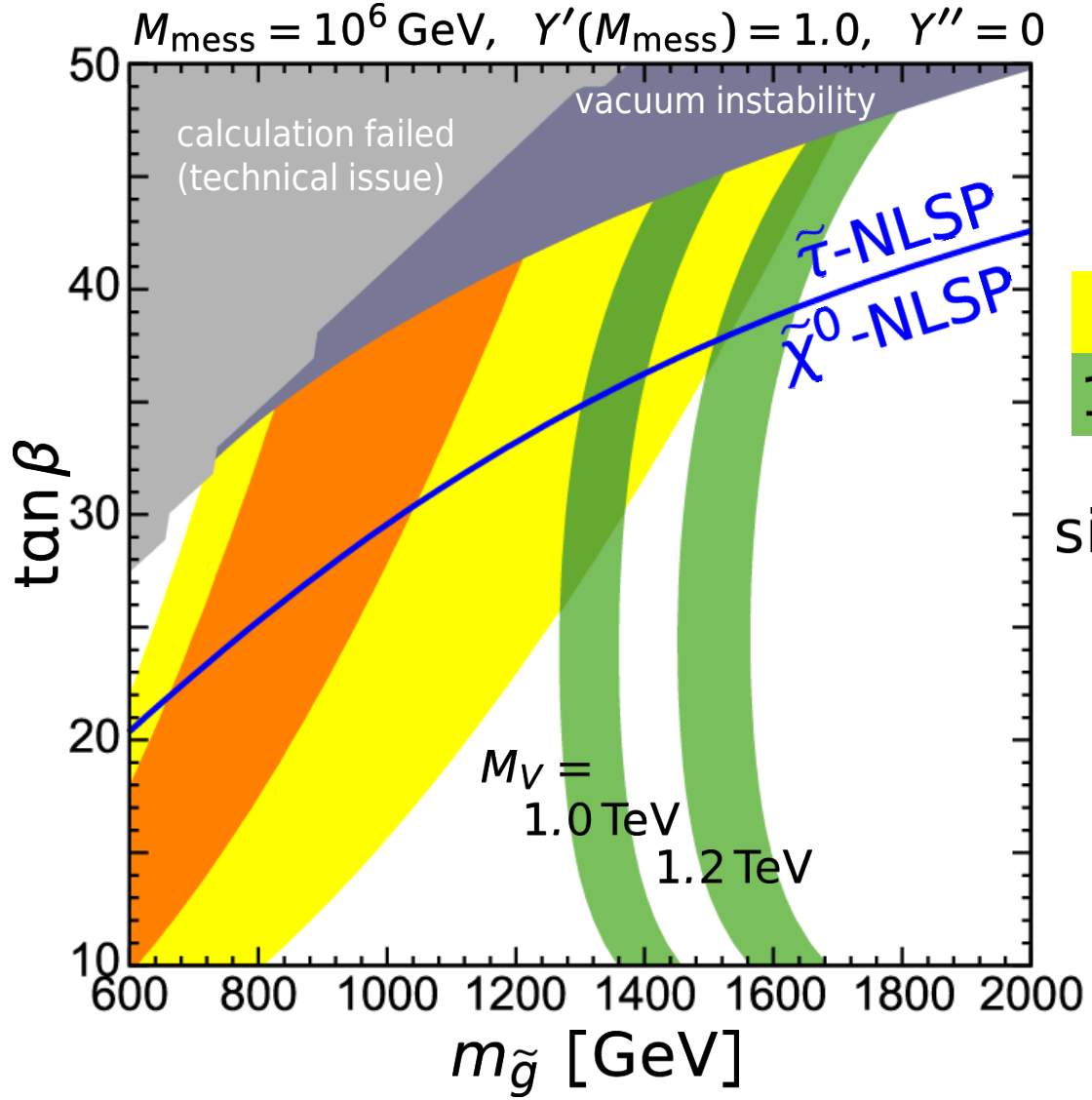
NLSP	Long-lived NLSP	NLSP prompt decay
$\tilde{\chi}_1^0$	jet + $\not{E}_T$ ($\tilde{\chi}_1^0\tilde{\chi}_1^0$) (same as mSUGRA)	jet + $\not{E}_T$ and $2\gamma + \not{E}_T$ (from $\tilde{\chi}_1^0 \to \gamma\tilde{G}$)
$\tilde{\tau}_1$	Long-lived stau	multi-tau

- Our analysis
  - Neutralino NLSP
    - → ATLAS 8 TeV-5.8 fb^{-1} (2–6 jets + $\not{E}_T$) [ATL-CONF-2012-109]
  - Stau NLSP
    - → CMS 7 TeV-5.0 fb^{-1} (assuming $pp \to \tilde{\tau}_1\tilde{\tau}_1^*$) ⇝ $m_{\tilde{\tau}_1} > 223$ GeV [1205.0272]



params: $(\Lambda,\ M_{\rm mess},\ \tan\beta,\ N_{\rm mess},\ {\rm sgn}\,\mu;\ \ Y',\ M_V)$

$N_{\rm mess} = 1$ + $\Delta(g\text{-}2)>0$; $Y' = 1.0$ (IR fixed)



$g-2$ 1σ 2σ

$125\,{\rm GeV} < m_h < 126\,{\rm GeV}$

simultaneous realization:

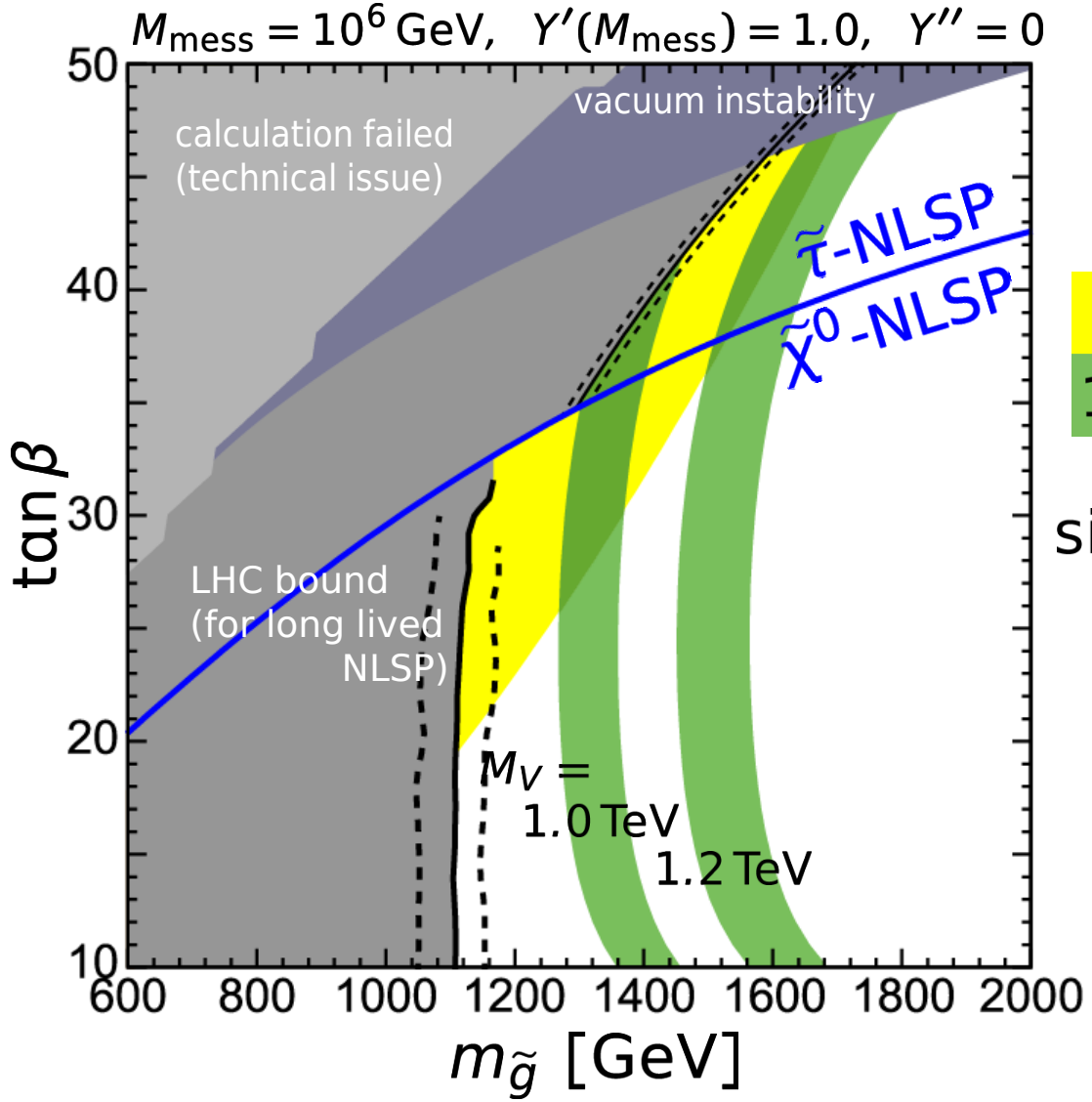
$M_V \lesssim 1.2\,{\rm TeV}$,

$m_{\tilde{g}} \lesssim 1.6\,{\rm TeV}$,

$\tan\beta \sim {\rm O}(10)$

params: $(\Lambda,\ M_{\rm mess},\ \tan\beta,\ N_{\rm mess},\ {\rm sgn}\,\mu;\ \ Y',\ M_V)$

$N_{\rm mess}=1$ + $\Delta(g\text{-}2)>0$; $Y'=1.0$ (IR fixed)



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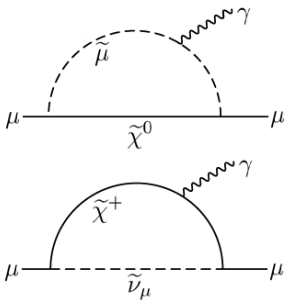
Summary?

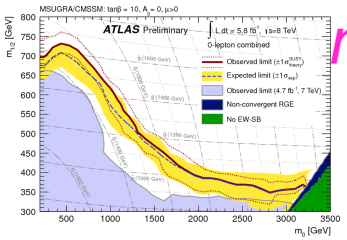
MSSM (Minimal SUSY Standard Model)

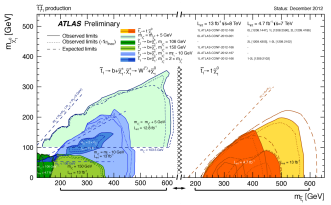
- 階層性問題 解決！
- 暗黒物質 候補あり！
- muon $g-2$ 説明できる！



↳ $m\left(\tilde{\chi}^0, \tilde{\chi}^\pm, \tilde{\mu}, \tilde{\nu}_\mu\right) \sim \mathrm{O}(100)\,\mathrm{GeV}$
and large $\tan\beta$??

- $m_h = 126\,\mathrm{GeV} \Longrightarrow m\left(\tilde{t}\right) \sim \mathrm{O}(1\text{–}10)\,\mathrm{TeV}$??
- Little hierarchy の議論 $\Longrightarrow m\left(\tilde{t}\right) \lesssim 1\,\mathrm{TeV}$??
- まだ見つかってない $\Longrightarrow m\left(\tilde{t}\right) \gtrsim 600\,\mathrm{GeV}$
  $m(\tilde{g}, \tilde{q}) \gtrsim 1\,\mathrm{TeV}$





MSSM (Minimal SUSY Standard Model)

- muon $g-2$ 説明できる！
  - $m\left(\tilde{\chi}^0, \tilde{\chi}^{\pm}, \tilde{\mu}, \tilde{\nu}_{\mu}\right) \sim \mathrm{O}(100)\,\mathrm{GeV}$
    and large $\tan\beta$??
- $m_h = 126\,\mathrm{GeV} \Longrightarrow m\left(\tilde{t}\right) \sim \mathrm{O}(1\text{–}10)\,\mathrm{TeV}$??

MSSM (Minimal SUSY Standard Model)

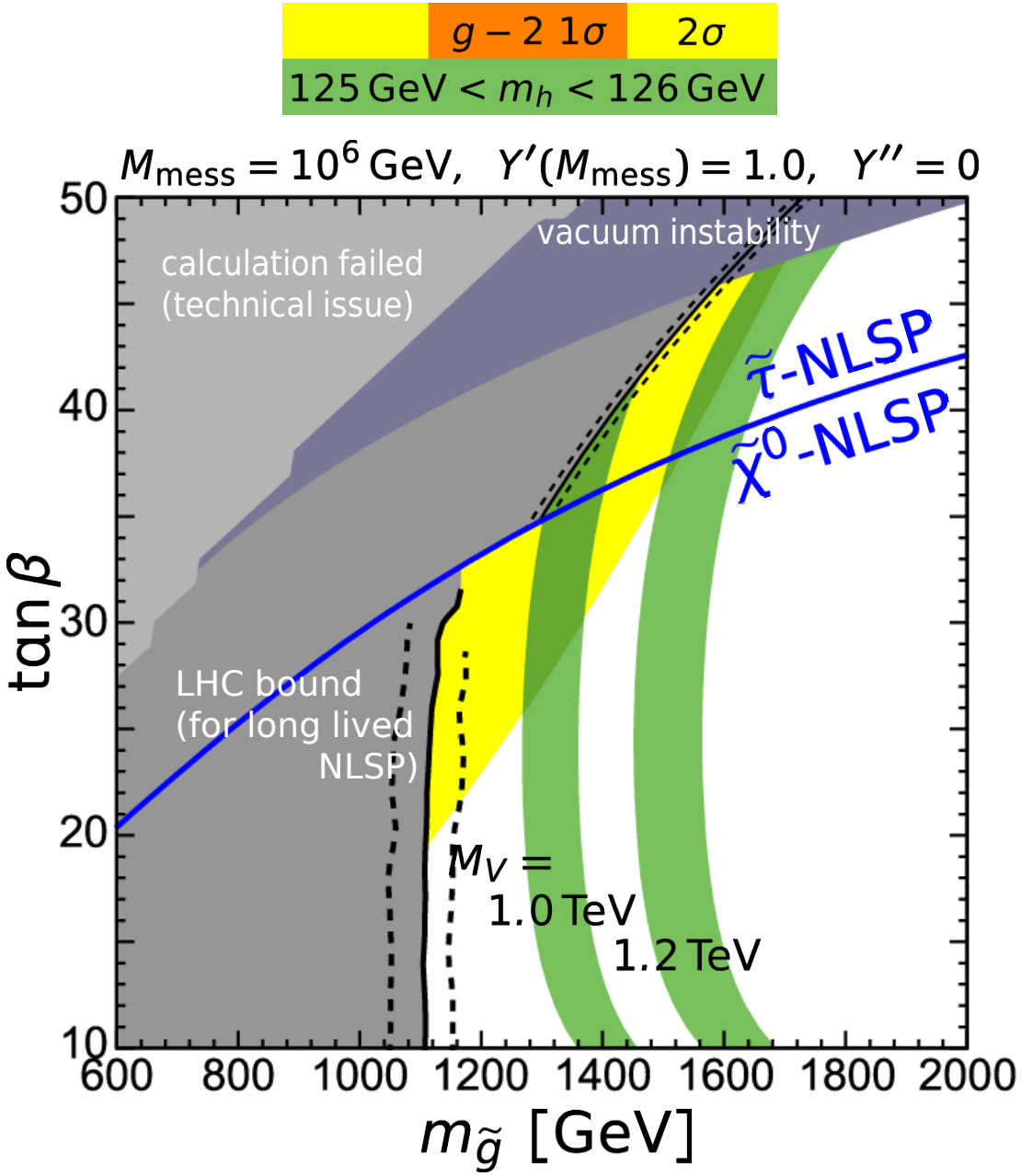
- muon $g-2$ 説明できる！
  - $m\left(\tilde{\chi}^0, \tilde{\chi}^{\pm}, \tilde{\mu}, \tilde{\nu}_{\mu}\right) \sim \mathrm{O}(100)\,\mathrm{GeV}$ and large $\tan\beta$??
- $m_h = 126\,\mathrm{GeV} \Longrightarrow m\left(\tilde{t}\right) \sim \mathrm{O}(1\text{–}10)\,\mathrm{TeV}$??

in conflict!

- ~~MSSM + more complicated SUSY~~
- Extended model + GMSB

V-MSSM = MSSM+($\mathbf{10} + \overline{\mathbf{10}}$), i.e. $\begin{cases} \mathbf{10} = (Q', \bar{U}', \bar{E}') \\ \overline{\mathbf{10}} = (\bar{Q}', U', E') \end{cases}$

➡ **Conflict Resolved!**



LHC constraints

- Extra quark searches

  $m_{t'_1} \gtrsim 300$–$650\,\mathrm{GeV}$

  (depending on decay modes)

  $m_{t'_1} \sim M_V - 87\,\mathrm{GeV}$,
  $pp \to t'_1 \bar{t}'_1, \qquad t'_1 \to (qW, qZ, qh)$

- SUSY searches

おまけ? 時間があれば。。。

$(g-2)_\mu$ 原理主義

- SUSY-breaking をややこしくしよう
  - GMSB だけど squark と slepton に効く messenger を変える
  - CMSSM なんだけど gluino だけ重くする

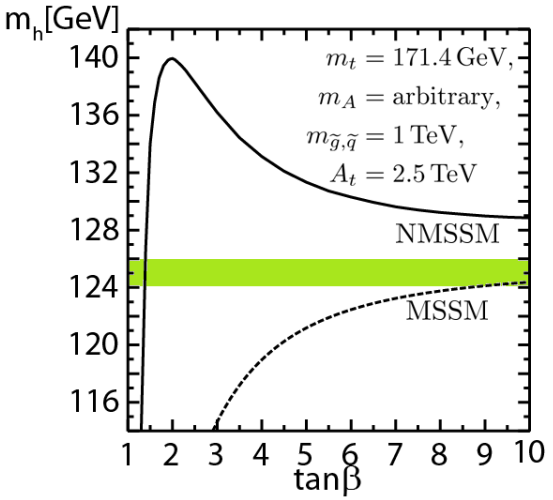
などなど。。。

- MSSM から拡張しよう

Gunion, Jiang, Kraml [1201.0982]
Ellwanger, Hugonie [1203.5048]

  - NMSSM → tanβが大きいと役に立たない
  - $\mathbf{10}+\overline{\mathbf{10}}$ (V-MSSM)
  - $\mathbf{5}+\overline{\mathbf{5}}$ → m_h は持ち上がりにくい → 軽いextra?
  - Extra U(1) gauge?
    → GUT がちょっと微妙になるのを許せばできる。

Endo, Hamaguchi, Iwamoto, Nakayama, Yokozaki [1112.6412]



Ellwanger, Hugonie [0612133]

Naturalness 原理主義

- NMSSM
  - + Mirage mediation

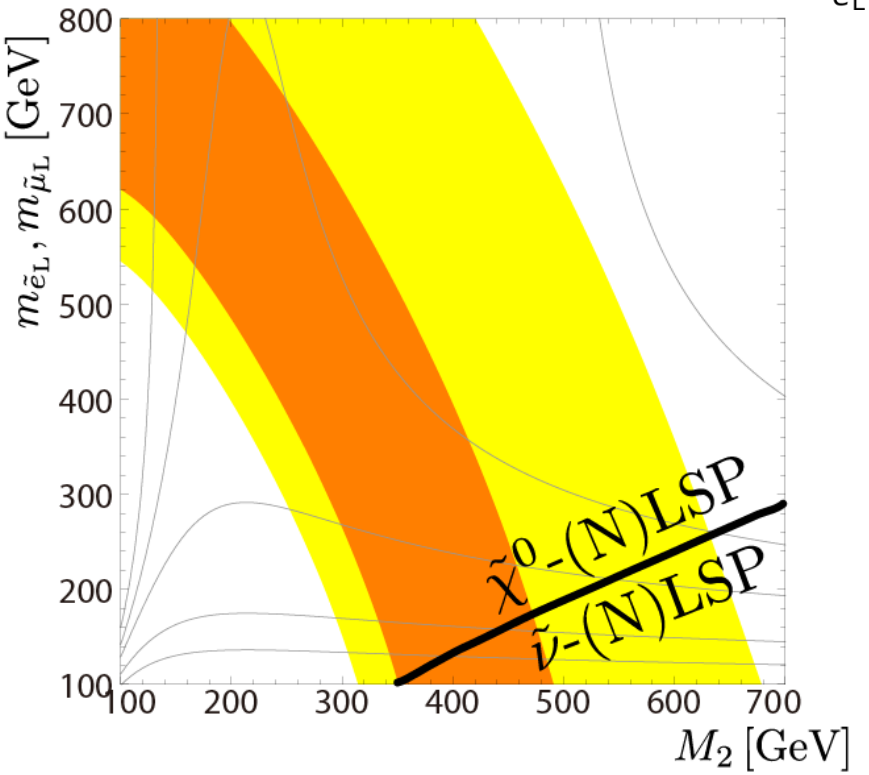
Asano, Higaki [1204.0508]
Kobayashi, Makino, Okumura, Shimomura, Takahashi [1204.3561]

Muon *g*-2 vs LHC

Endo, Hamaguchi, Iwamoto, Yoshinaga [1302.xxxx]

- $(g-2)_\mu \implies m\left(\tilde{\chi}^0, \tilde{\chi}^\pm, \tilde{\mu}, \tilde{\nu}_\mu\right) \sim \mathrm{O}(100)\,\mathrm{GeV}$
- こいつら直接見えない？

- squark/stau decoupled
- $\mu = 2\,\mathrm{TeV}, M_1 = M_2/2$
- $\tan\beta = 40, M_A = 1500\,\mathrm{GeV}$
- $m^2_{\tilde{e}_\mathrm{L}} : m^2_{\tilde{e}_\mathrm{R}} = 4:9$



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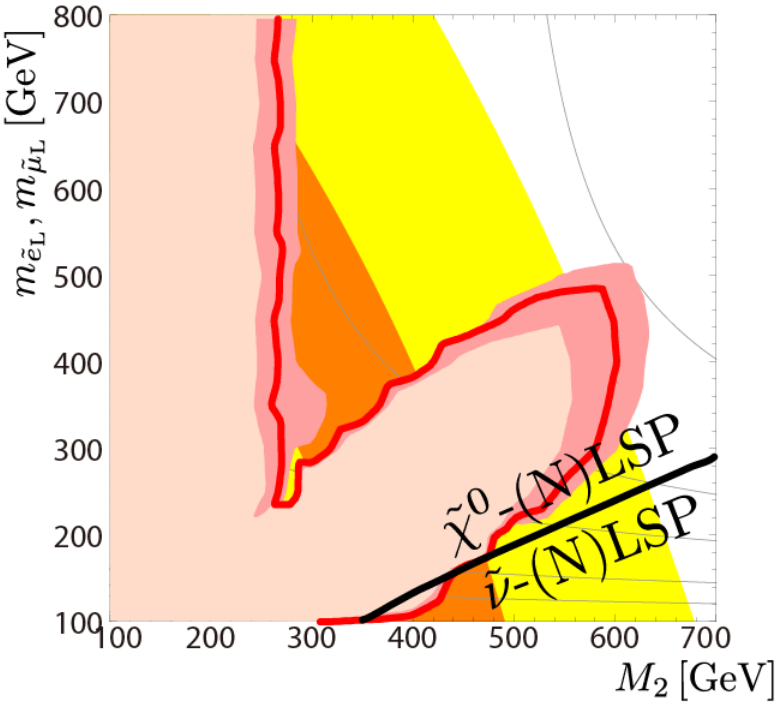
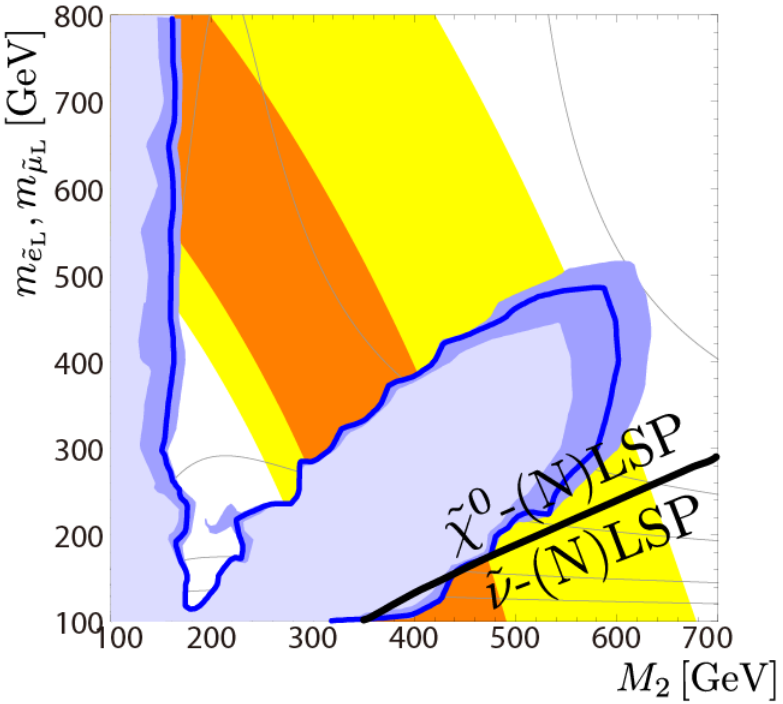


$M_3 = 3M_2$



gluino decoupled