$(g-2)_\mu$ anomaly & 125GeV Higgs :

Extra vector-like quark & LHC prospects

(added to MSSM)

Sho IWAMOTO（岩本　祥）

The University of Tokyo, JAPAN

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@ GUT 2012 (YITP)

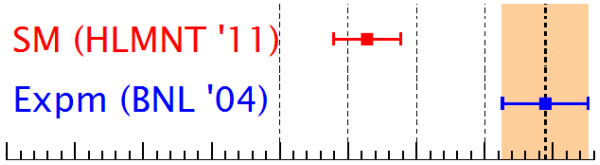
Based on

M. Endo, K. Hamaguchi, S.I., N. Yokozaki. [1112.5653]

Also See: Endo, Hamaguchi, SI, Yokozaki. [1108.3071][1202.2751]

Endo, Hamaguchi, SI, Nakayama, Yokozaki. [1112.6412]

muon $g-2$

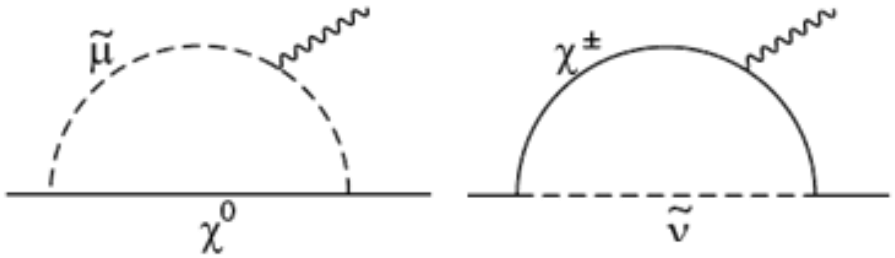


3.3σ discrepancy

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

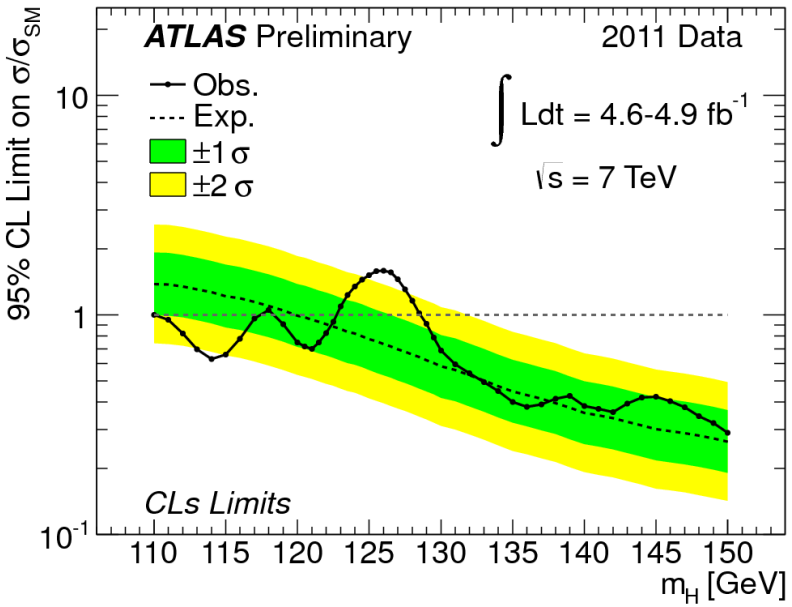
Possible explanation

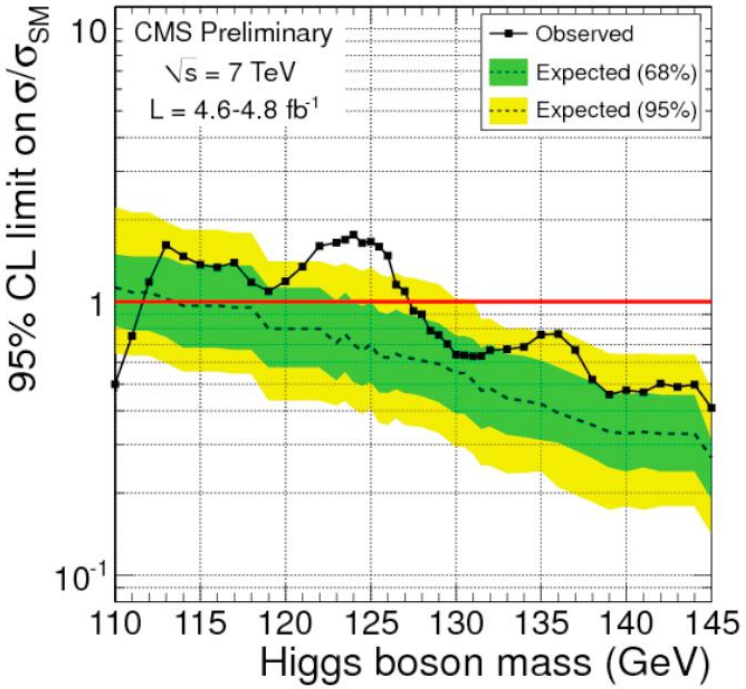
SUSY with light superparticles.



We've got a feeling we're having

125GeV Higgs.



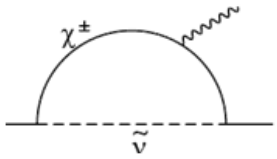


(Rencontres de Moriond EW, Mar. 2012)

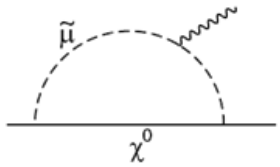
[3]

(Discussed in Prof. Nath's talk.)

$(g-2)_\mu$ in MSSM



$$\approx \frac{\alpha_w m_\mu^2}{m_{\rm soft}^2}\,{\rm sgn}(\mu M_2)\tan\beta,$$



$$\approx \frac{\alpha_Y m_\mu^2}{m_{\rm soft}^2}\,{\rm sgn}(\mu M_1)\tan\beta + \cdots$$

125GeV in MSSM

$$m_h^2 \lesssim m_Z^2 + \frac{3g_W^2 m_t^4}{8\pi^2 m_W^2}\left[\ln\frac{M_S^2}{m_t^2} + \alpha^2\left(1-\frac{\alpha^2}{12}\right)\right]$$

(1-loop level)

where $M_S^2 := \dfrac{M_{\tilde{t}_1}^2 + M_{\tilde{t}_2}^2}{2}$, $\alpha := \dfrac{A_t - \mu\cot\beta}{M_S}$.

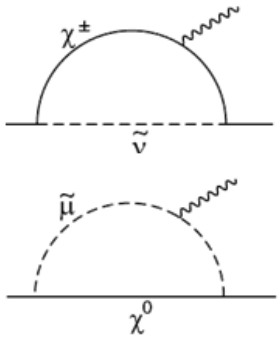
dilemma (GUT)

- light $(\tilde{\nu}_\mu, \tilde{\chi}^\pm)$ or $(\tilde{\mu}, \tilde{\chi}^0)$ ⟷ heavy $\tilde{t}$
- large $\tan\beta$ → large $(A_t - \mu\cot\beta)$

(roughly $\approx -\sqrt{6}m_{\tilde{t}}$)

(Discussed in Prof. Nath's talk.)

$(g-2)_\mu$ in MSSM



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(roughly $\approx -\sqrt{6}m_{\tilde{t}}$)

In the MSSM set-up,

Impossible

within
- GMSB
- CMSSM
- NUHM

Possible with **tuning**:
- $M_1 \neq M_2 \neq M_3$ @GUT
- $m_0^{\text{1,2-gen.}} < m_0^{\text{3rd}}$ @GUT

etc…

(Note: $b \to s\gamma$ & vacuum stability constraint A_t.)

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

For 125GeV & g-2, we must...

- **tune** the parameter in ~~SUSY~~ models
- **ignore** $(g-2)_\mu$ anomaly.
  - "It is just from hadronical uncertainty, theorists' fault!!"
- **wish** a lighter Higgs.
- **extend** the MSSM.
  - NMSSM
  - add $\mathbf{5}+\overline{\mathbf{5}}$
  - add $\mathbf{10}+\overline{\mathbf{10}}$
  - add a new gauge symmetry.

For 125GeV & g−2, we must…

- **tune** the parameter in ~~SUSY~~ models
- **ignore** $(g-2)_\mu$ anomaly.
  - "It is just from hadronical uncertainty, theorists' fault!!"
- **wish** a lighter Higgs.
- **extend** the MSSM.
  - ~~NMSSM~~ $g-2 \Rightarrow$ large $\tan\beta \Rightarrow$ NMSSM not contribute.
  - ~~add $\mathbf{5}+\overline{\mathbf{5}}$~~ is still inadequate. Martin [0910.2732]
  - add $\mathbf{10}+\overline{\mathbf{10}}$ **Today's topic.** [1112.5653]
  - add a new gauge symmetry. ← See: Endo, Hamaguchi, SI, Nakayama, Yokozaki [1112.6412]

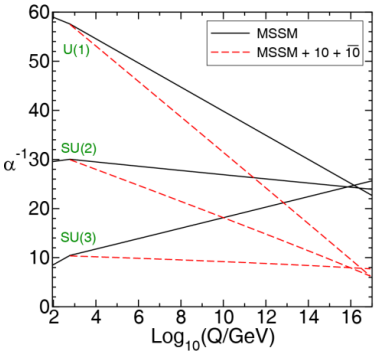
2. The Extension we propose

Okada, Moroi (1992); we dug up again in the context "higgs & g-2".

Extension w. Vector-like Matters

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

- No gauge anomaly.
- Gauge couplings unification.



Martin [0910.2732]

$m_h \Uparrow$ $\qquad$ $m_h \Downarrow \longrightarrow$ we *assume* $Y'' \ll 1$.

$$W_{\text{add}} = Y' Q' H_{\text{u}} U' + Y'' \bar{Q}' H_{\text{d}} \bar{U}' + M_V Q' \bar{Q}' + M_V U' \bar{U}' + M_V E' \bar{E}'$$

$$W_{\text{mix}} = \epsilon_i Q_i H_{\text{u}} U' + \epsilon'_i Q' H_{\text{u}} \bar{U}_i + \epsilon''_i Q' H_{\text{d}} \bar{D}_i$$

Mixing between SM- & vector-like quark

- Too large $\longrightarrow$ flavor problem.
- No mixing $\longrightarrow$ stable colored particle.

$\Rightarrow$ *assumed* very small.

- $\boldsymbol{Y' = 1.05}$: infrared fixed point $\Rightarrow$ nice for 125 GeV

  (also A_t and A' go to IR fixed point.)

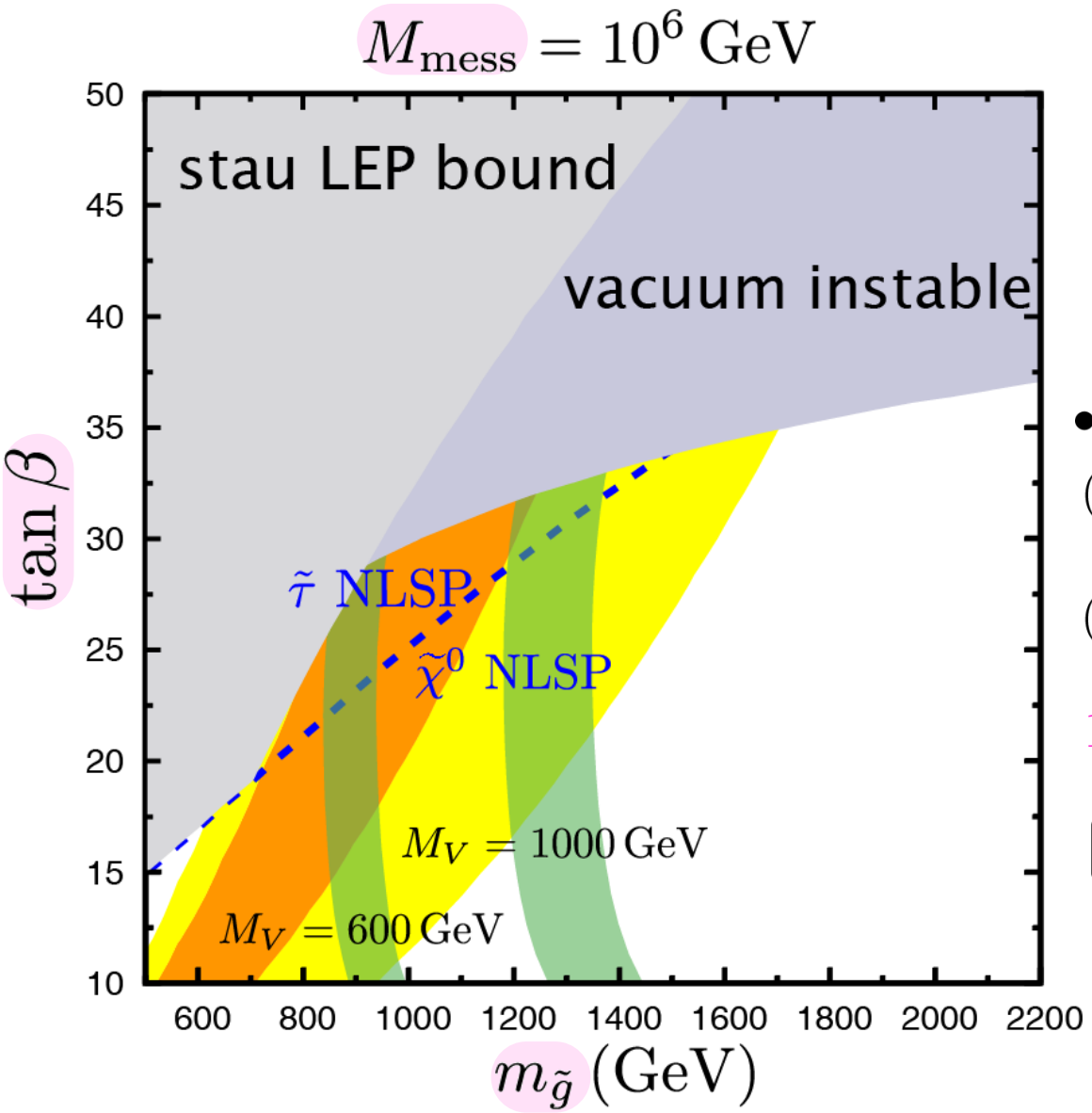
- Several tunings $\cdots$ **WANTED**: UV models to solve them.

RESULT

in this talk

with { GMSB framework
CMMSM framework

[10]



$g-2$ 1σ 2σ

$124\,\text{GeV} < m_h < 126\,\text{GeV}$

- Parameters

$(\Lambda,\ M_{\rm mess},\ \tan\beta,\ N_{\rm mess},\ \text{sgn}\,\mu)$;

$\|$ $\|$

1 $+$

$(Y',\ M_V)$

$\|$

1.05(IR fixed point)

to keep perturvative till $M_{\rm GUT}$

to explain $(g-2)_\mu$

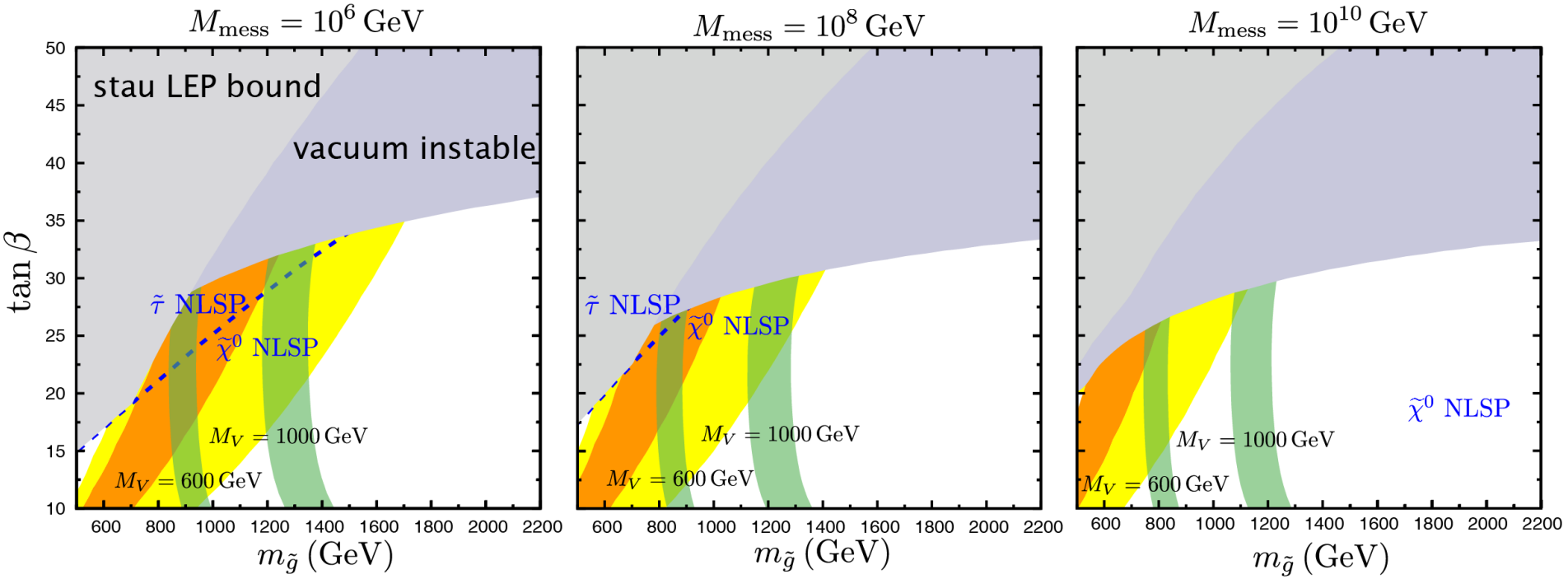
$g-2$ 1σ 2σ

$124\,\mathrm{GeV} < m_h < 126\,\mathrm{GeV}$

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

$\|\quad\quad\|\quad\quad\|$

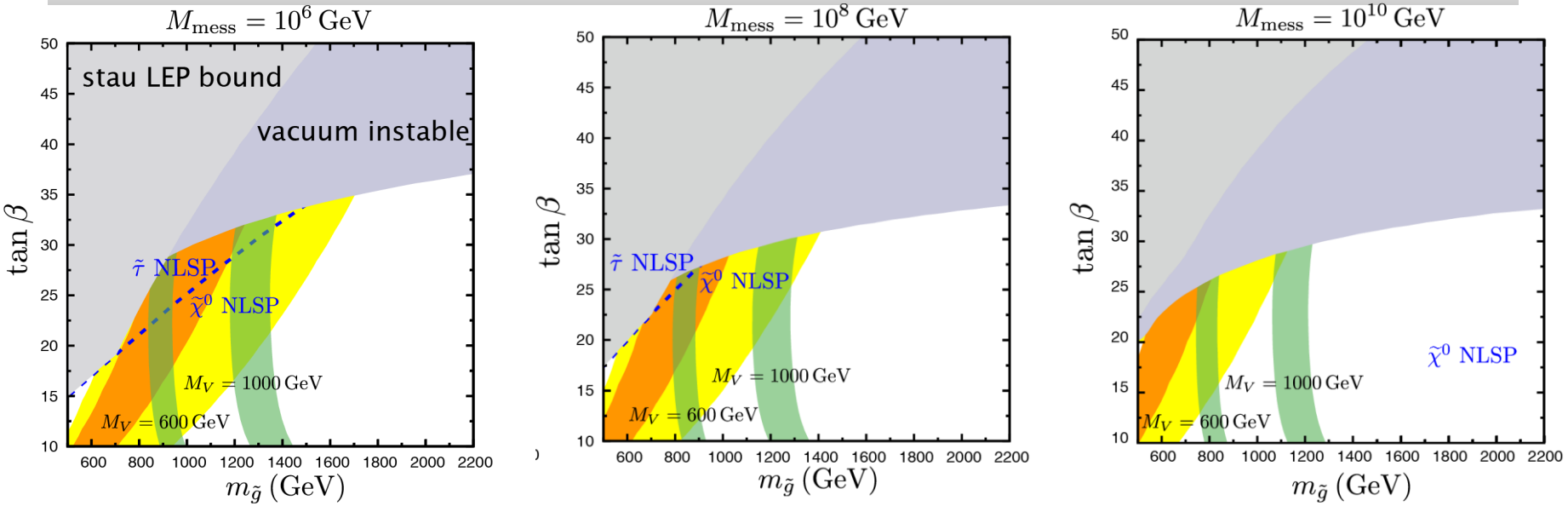
$1\quad\ +\quad 1.05$



- $(g-2)_\mu$ 2σ-level $\cdots$ $M_V \lesssim 1.5\,\mathrm{TeV},\ \ m_{\tilde{g}} \lesssim 1.6\,\mathrm{TeV}$
- 1σ-level $\cdots$ $M_V \lesssim 1.0\,\mathrm{TeV},\ \ m_{\tilde{g}} \lesssim 1.2\,\mathrm{TeV}$

3. LHC Phenomenology

SUSY search



- SUSY signal $\Longleftarrow$ NLSP / NLSP lifetime

  $(\widetilde{\chi}_1^0$ or $\widetilde{\tau}_1)$ (long-lived or prompt-decay)

- $(g-2)_\mu \Longrightarrow$ lighter SUSY

  $\Longrightarrow$ Parameter space will easily be covered.

Cf.) ATLAS [1111.4116], [1109.6572]; CMS [SUS-11-008] ;
Long-lived stau regions are already excluded. (CMS Seminar Jan. 2012)

Vector-like Quark Search

direct proof!

- New "vector-like" quark (t'_1, b', t'_2)

$$\mathbf{10} = (Q', U', E')$$
$$\overline{\mathbf{10}} = (\bar{Q}', \bar{U}', \bar{E}')$$

Mass

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

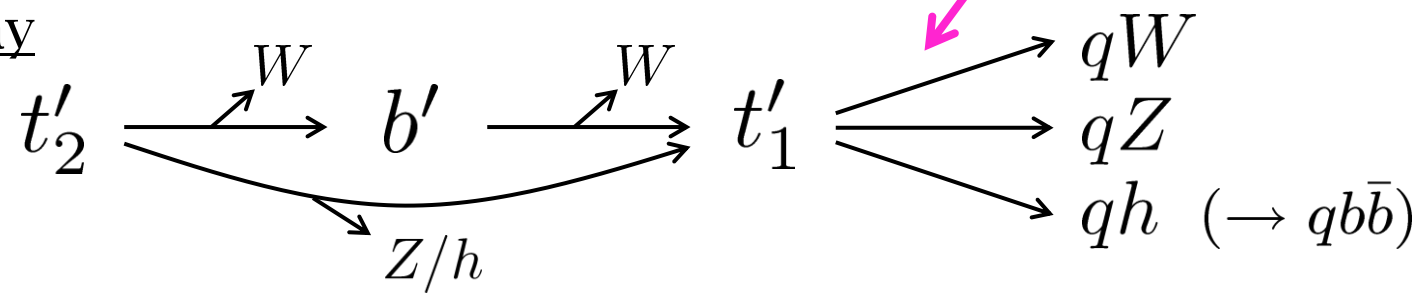
$$W_{\mathrm{add}} = Y' Q' H_{\mathrm{u}} U' + Y'' \bar{Q}' H_{\mathrm{d}} \bar{U}' + M_V Q' \bar{Q}' + M_V U' \bar{U}' + M_V E' \bar{E}'$$
$$W_{\mathrm{mix}} = \epsilon_i Q_i H_{\mathrm{u}} U' + \epsilon'_i Q' H_{\mathrm{u}} \bar{U}_i + \epsilon''_i Q' H_{\mathrm{d}} \bar{D}_i$$

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

Production

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

Decay



Vector-like Quark Search

- New "vector-like" quark (t'_1, b', t'_2)

$pp \to t'_1 \bar{t}'_1; \quad t'_1 \to qW, qZ, qh \ (\to q b\bar{b})$

Current bound

if it decays exclusively as

$t'_1 \to bW \ :: m_{t'_1} > 552\,\text{GeV}$ CMS 4.7fb^{-1} [EXO-11-050]

$t'_1 \to q_d W :: m_{t'_1} > 340\,\text{GeV}$ CDF 5.6fb^{-1} [1107.3875]

$t'_1 \to tZ \ :: m_{t'_1} > 475\,\text{GeV}$ CMS 1.14fb^{-1} [1109.4985]

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

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

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

No general bound on t'_1 yet because of these possibility.

≥ 4 b-quarks $(h \to b\bar{b})$

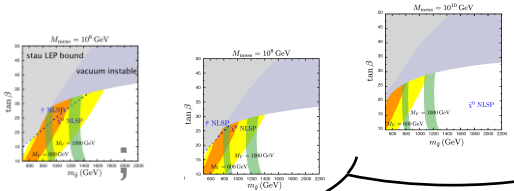
Interesting channel after Higgs discovery.

4. Conclusion

Conclusion

125GeV higgs? $+$ $(g-2)_\mu$

MSSM $+$ $\mathbf{10}+\overline{\mathbf{10}}$: vector-like quarks



utopian theorists

Our ~~delusion~~ dream will be smashed/proved by

- SUSY search
- 4th gen. quark search
  - $t' \to qW$
  - $t' \to qZ$
  - $\boldsymbol{t' \to qh}(\to q + b\bar{b})$ **at the LHC**