Enhancement of the Higgs mass in SUSY model with extra matters

Takeo Moroi (Tokyo)

Refs:

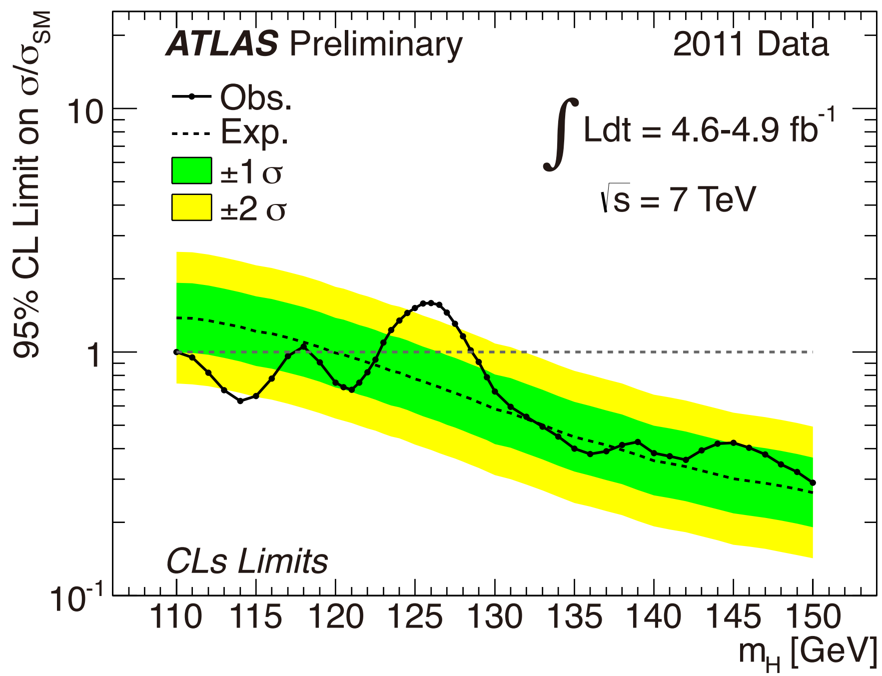
Asano, Moroi, Sato & Yanagida, PLB 705 (2011) 337

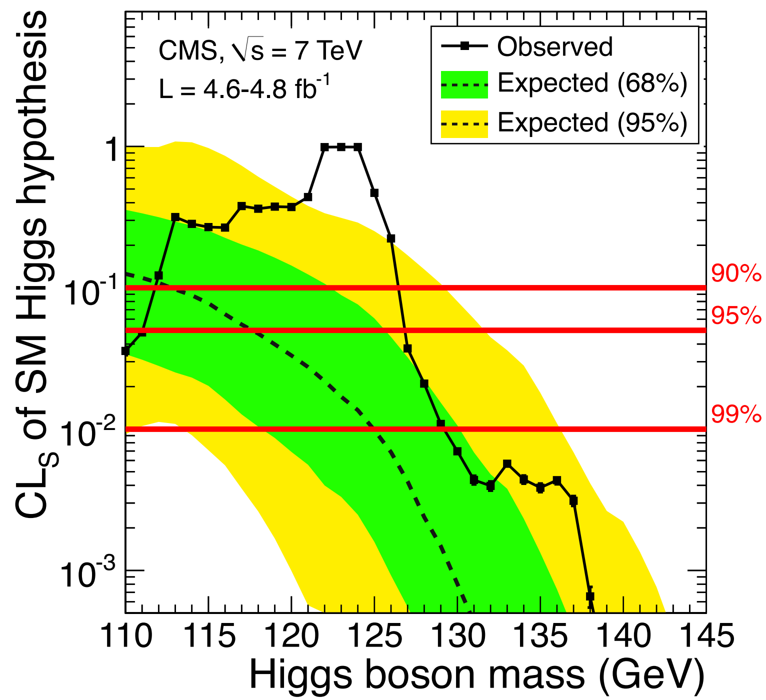
Moroi, Sato & Yanagida, PLB 709 (2012) 218

1. Introduction

Recent (interesting) news from the LHC:

Higgs-like signal at $m_h \simeq 125$ GeV

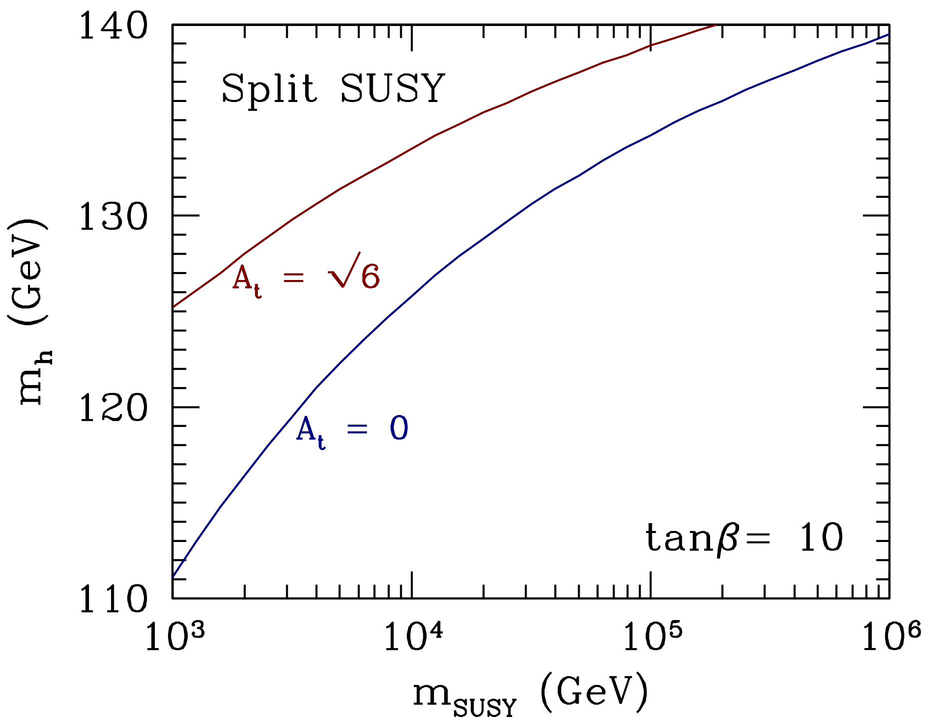




Left: ATLAS [ATLAS-CONF-2012-019]; Right: CMS [arXiv:1202.1488]

$\Rightarrow$ Significant implication to SUSY models, if $m_h \simeq 125$ GeV

For $m_h \simeq 125$ GeV, heavy $\tilde{t}$ or large A_t is needed in the MSSM



Enhancement of m_h in models beyond the MSSM:

1. Extra tree-level interaction $\Rightarrow$ NMSSM, extra $U(1)$, $\cdots$
2. Extra radiative correction $\Rightarrow$ Extra Matter

Today I consider the MSSM with extra matters

- Higgs mass
- Other low energy observables (muon $g-2$, Ω_{LSP})
- Model building issues (why extra matters)

<u>Outline</u>

1. Introduction
2. Model
3. Higgs mass, muon $g-2$, Ω_{LSP}
4. Why extra matters at the EW scale?
5. Summary

2. Model

Model: MSSM with 1-pair of $\mathbf{10}+\bar{\mathbf{10}}$ of $SU(5)_{\rm GUT}$

	$SU(3)_C$	$SU(2)_L$	$U(1)_Y$
Q	$\mathbf{3}$	$\mathbf{2}$	$1/6$
U	$\bar{\mathbf{3}}$	$\mathbf{1}$	$-2/3$
E	$\mathbf{1}$	$\mathbf{1}$	1
$\bar{Q}$	$\bar{\mathbf{3}}$	$\mathbf{2}$	$-1/6$
$\bar{U}$	$\mathbf{3}$	$\mathbf{1}$	$2/3$
$\bar{E}$	$\mathbf{1}$	$\mathbf{1}$	-1

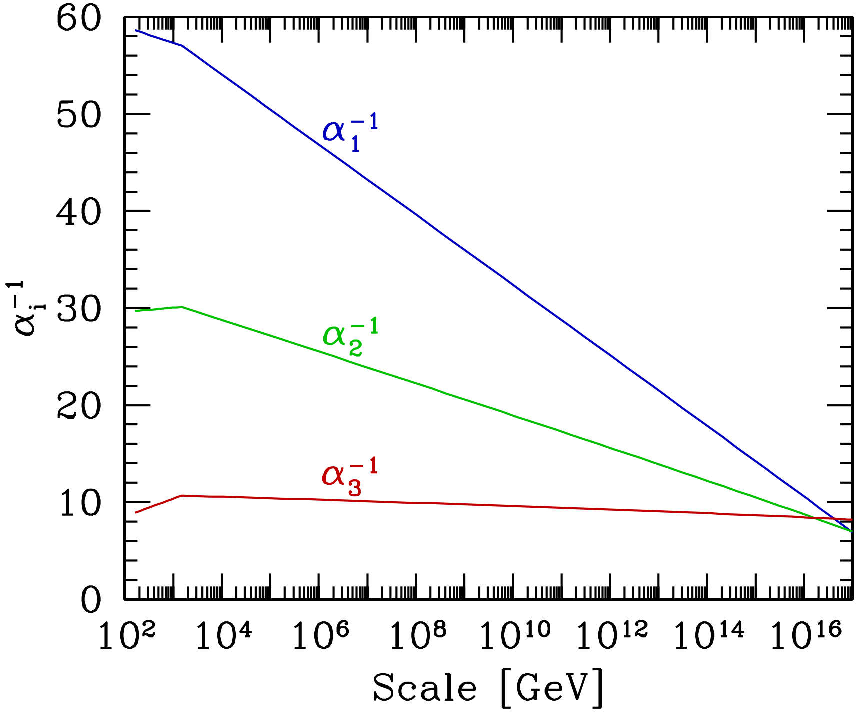
- New Yukawa interaction may exist:

$$W = W^{(\rm MSSM)} + y_U Q U H_u + \cdots$$

y_U: New Yukawa coupling constant

Extra matters: Complete multiplets of $SU(5)_{\mathrm{GUT}}$

- Unification of gauge coupling constants holds



- β-function of $SU(3)_C$ vanishes at 1-loop level

  $\Rightarrow SU(3)_C$ is quite strong up to the unification scale

Superpotential:

$$W = W^{(\text{MSSM})} + y_U Q U H_u + M_Q \bar{Q} Q + M_U \bar{U} U + M_E \bar{E} E$$

y_U: New Yukawa coupling constant

M_Q, M_U, M_E: New mass parameters ($\lesssim 1$ TeV)

Soft SUSY breaking terms:

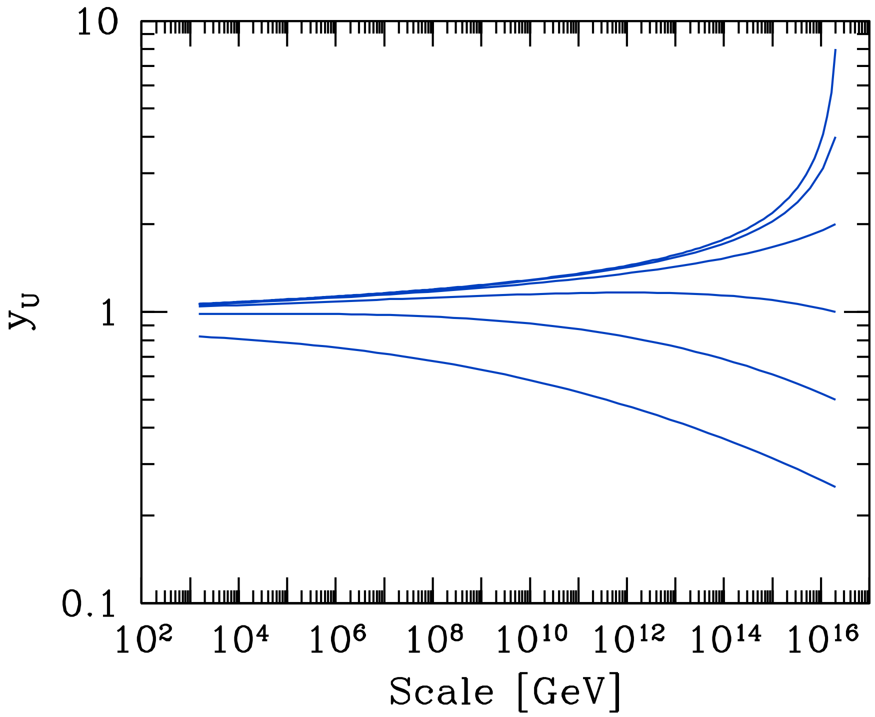
$$\mathcal{L}_{\text{soft}} = \mathcal{L}_{\text{soft}}^{(\text{MSSM})} + m_{\tilde{Q}}^2 |\tilde{Q}|^2 + m_{\tilde{\bar{Q}}}^2 |\tilde{\bar{Q}}|^2 + m_{\tilde{U}}^2 |\tilde{U}|^2 + m_{\tilde{\bar{U}}}^2 |\tilde{\bar{U}}|^2 + \cdots$$

$SU(3)_C$ is quite strong up to the GUT scale ($b_3^{\text{1-loop}} = 0$)

$\Rightarrow$ y_U- and A-parameters approach their IR fixed-point

[Martin ('10)]

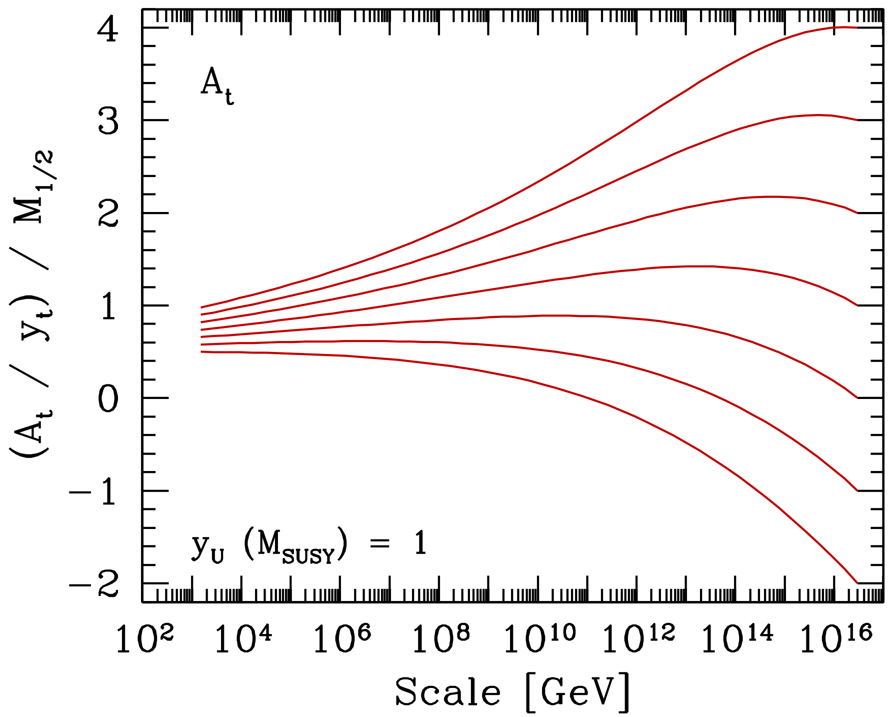
Running of y_U

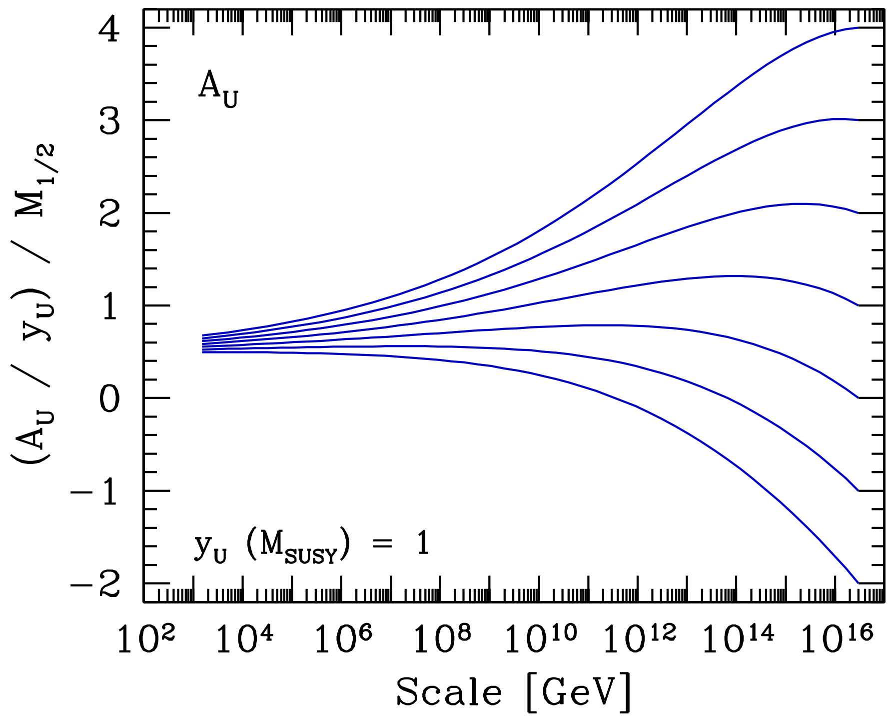


$y_U \simeq 1$ is the IR fixed point (at the TeV scale)

$\Rightarrow$ Large radiative correction on m_h is expected

Running of tri-linear coupling constants





A_t and A_U become smaller than squark masses at the TeV scale

$\Rightarrow$ They are not so important for the enhancement of m_h

3. Higgs mass, muon $g-2$, Ω_{LSP}

Radiative correction due to the extra matters enhances m_h

[Moroi & Okada ('92); Martin ('10)]

$$\Delta V^{(\text{extra})} = \frac{3}{32\pi^2}\mathrm{Tr}\left[\left(\mathcal{M}^2_{\tilde{Q},\tilde{U},\tilde{\bar{Q}},\tilde{\bar{U}}}\right)^2\left\{\ln\left(\frac{\mathcal{M}^2_{\tilde{Q},\tilde{U},\tilde{\bar{Q}},\tilde{\bar{U}}}}{\mu^2}\right)-\frac{3}{2}\right\}\right] - \frac{3}{32\pi^2}\mathrm{Tr}\left[\left(\mathcal{M}^2_{Q,U,\bar{Q},\bar{U}}\right)^2\left\{\ln\left(\frac{\mathcal{M}^2_{Q,U,\bar{Q},\bar{U}}}{\mu^2}\right)-\frac{3}{2}\right\}\right]$$

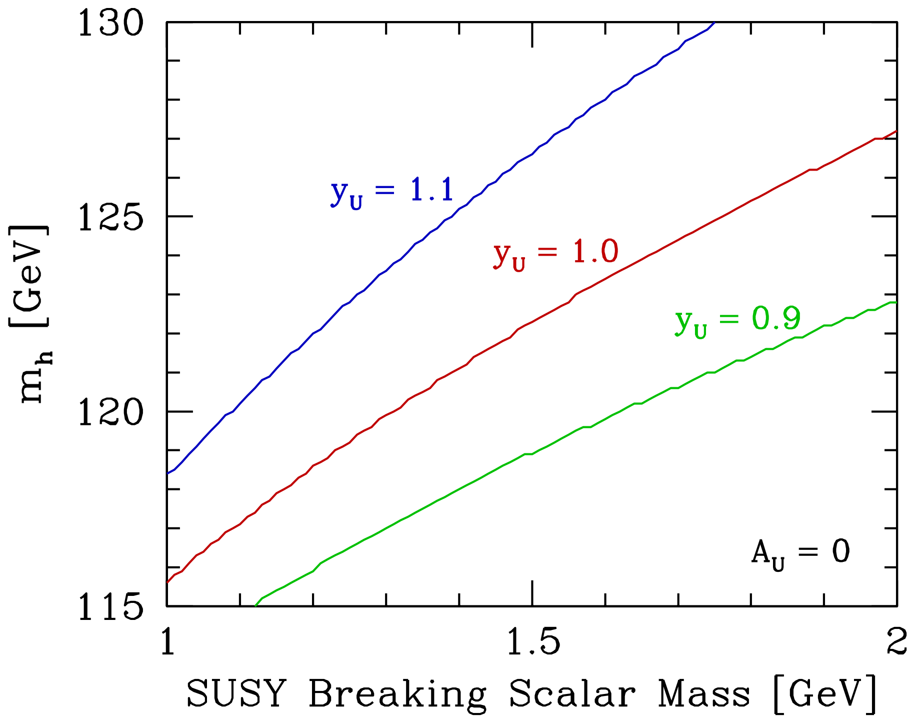
- Higgs mass is enhanced when $M_{Q,U} \ll m_{\tilde{Q},\tilde{U}}$

$$\Delta m_h \sim \frac{3v^2}{16\pi^2 m_h} y_U^4 \log\frac{M^2_{Q,U} + m^2_{\tilde{Q},\tilde{U}}}{M^2_{Q,U}}$$

- A-parameters are small, so they are not so important

m_h can be significantly enhanced in the present setup

m_h is evaluated by using RGE analysis



- $\tan\beta = 30$
- $M_U = M_Q = 650$ GeV

$\Rightarrow$ $m_h \simeq 125$ GeV can be realized even if the perturbativity up to the GUT scale is required (i.e., $y_U \lesssim 1$)

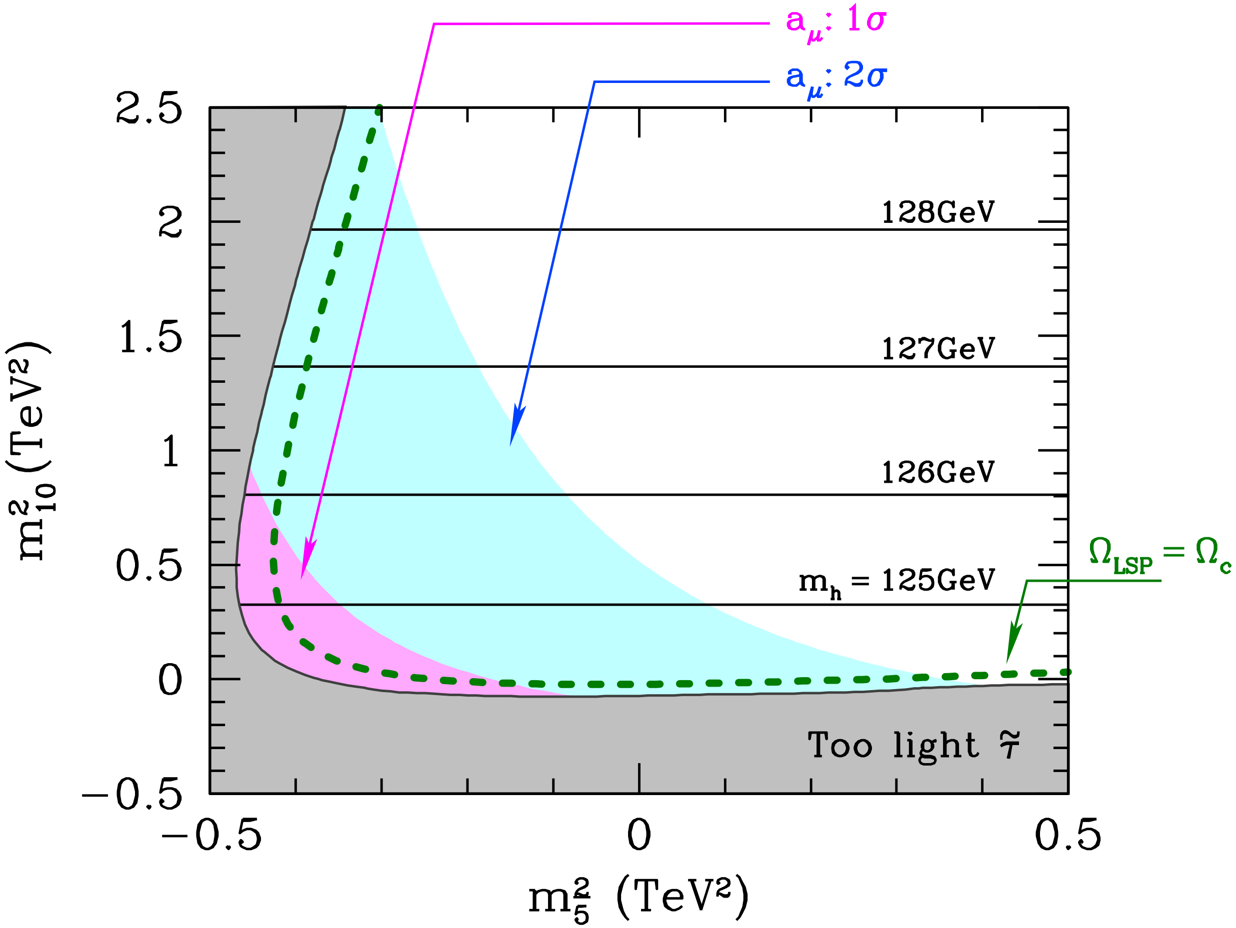
$m_h \simeq 125$ GeV vs. other requirements

- Consistency with $SU(5)$ unification
- Muon $g-2$: $a_\mu^{(\mathrm{exp})} - a_\mu^{(\mathrm{SM})} = (25.9 \pm 8.1) \times 10^{-10}$
  [Cho, Hagiwara, Matsumoto & Nomura ('11)]
- Relic density of the LSP (in this case, neutralino)

Analysis with a simple boundary condition (at the GUT scale)

- Universal gaugino mass: $M_{1/2}$
- Universal scalar mass-squared for $\bar{\mathbf{5}}$-matters: $m_{\bar{\mathbf{5}}}^2$
- Universal scalar mass-squared for $\mathbf{10}$ and $\bar{\mathbf{10}}$: $m_{\mathbf{10}}^2$
- Higgs mass-squared: $m_{\mathbf{5}_H}^2$ and $m_{\bar{\mathbf{5}}_H}^2$
- A-parameters $= 0$

m_h, muon $g-2$, and $\Omega_{\rm LSP}$ on $m^2_{\bar{\mathbf{5}}}$ vs. $m^2_{\mathbf{10}}$ plane



- $\tan\beta = 50$
- $M_U = M_Q = 650$ GeV
- $m_{\mathbf{5}_H} = m_{\bar{\mathbf{5}}_H} = 0$
- $A_0 = 0$
- $M_{1/2} \simeq 1.3$ TeV

$\Rightarrow$ $M_{\rm gluino} = 900$ GeV

$\Rightarrow$ $M_{\rm Bino} = 210$ GeV

$\Rightarrow$ m_h, a_μ, and $\Omega_{\rm LSP}$ can take phenomenologically preferred values, taking $m^2_{\bar{\mathbf{5}}} < 0$

4. Why Extra Matters at Electroweak Scale?

How to suppress Planck-scale mass of vector-like matters?

$\Leftrightarrow$ One possibility: discrete R-symmetry $Z_N^{(R)}$ (with $Z > 2$)

Example: $Z_4^{(R)}$

		MSSM				extra matters	
	θ	$\Phi_{\mathbf{10}}$	$\Phi_{\bar{\mathbf{5}}}$	$H_{\mathbf{5}}$	$H_{\bar{\mathbf{5}}}$	$\Phi'_{\mathbf{10}}$	$\Phi'_{\overline{\mathbf{10}}}$
$SU(5)_{\text{GUT}}$	$-$	$\mathbf{10}$	$\bar{\mathbf{5}}$	$\mathbf{5}$	$\bar{\mathbf{5}}$	$\mathbf{10}$	$\overline{\mathbf{10}}$
$Z_4^{(R)}$-charge	1	1	1	0	0	1	-1

- Fundamental mass terms of extra matters as well as μ-term are not allowed in the superpotential
- $M_{Q,U,E}$ can be from Giudice-Masiero mechanism

  $\Leftrightarrow K_{\text{GM}} = \kappa \bar{Q} Q + \cdots$ is allowed by $Z_4^{(R)}$
- Dangerous B-violating $D = 5$ operators are forbidden

Extra matters are needed if $Z_N^{(R)}$ is non-anomalous

$\Rightarrow$ Anomaly cancellation for $Z_N^{(R)}[SU(2)_L]^2$

[Ibanez & Ross ('91)]

$$\sum_i T_i^{SU(2)_L}(q_i + k_i N) = 0$$

$$\Rightarrow \quad \sum_i T_i^{SU(2)_L} q_i = \frac{1}{2}(-2) + 2 + \frac{3}{2}(-2) n_{\mathbf{10}} = \frac{N}{2} k$$

q_i: $Z_N^{(R)}$-charge of i-th fermion (i.e., charge of boson -1)

$n_{\mathbf{10}}$: The number of $\mathbf{10} + \bar{\mathbf{10}}$ extra matter pairs

k_i & k: integers

$\Rightarrow$ No solution if $n_{\mathbf{10}} = 0$ (because $N = 4$)

$\Rightarrow$ $n_{\mathbf{10}} = 1$ gives a consistent solution ($k = -1$)

$Z_N^{(R)}$ cannot be embedded into non-anomalous $U(1)_R$, if

- The particle content: MSSM
- Giudice-Masiero mechanism for the μ-term
- Quarks and leptons are embedded into $SU(5)$ multiplets

  $\Leftrightarrow$ In fact, product-group GUT is necessary

Possibilities to realize non-anomalous discrete R-symmetry

- Extra matters

  [Kurosawa, Maru & Yanagida ('01); Asano, Moroi, Sato & Yanagida ('11)]
- Green-Schwarz mechanism

  [Lee, Raby, Ratz et al. ('10, '11)]
- Give up some of above assumptions

5. Summary

Today, I considered SUSY model with extra matters

- Higgs mass can be enhanced
- Muon $g-2$ and dark matter density may be explained

One possibility to realize extra matters at the EW scale

- Non-anomalous discrete R-symmetry

The model can be tested at the LHC

- Gluino can be within the LHC reach
- Extra matters can be produced at the LHC