A New Extension of MSSM: FMSSM

S. Nandi

Oklahoma State University
and
Oklahoma Center for High Energy Physics

April 29, 2008

(in collaboration with Z. Tavartkiladze)
arXiv: 0804.1996[hep-ph]

Goals

- To explain why $m_b, m_\tau \ll m_t$ in the framework of MSSM
- Higgs sector different from MSSM
  (ex. fermiophodic and gauge-phobic heavy Higgs sector)
  $\Rightarrow$ seem like SM Higgs
- Extend the dark matter region allowed in usual MSSM
- Keep gauge coupling unification
- New interesting phenomenology at the LHC

Model & Formalism

- Consider 3rd family: $\hat{q}_3, \hat{u}_3^c, \hat{d}_3, \hat{l}_3, \hat{e}_3^c$ and two Higg doublet: $\hat{h}_u, \hat{h}_d$
- Usual MSSM Yukawa couplings

$$W = \lambda_t \hat{q}_3 \hat{u}_3^c \hat{h}_u + \lambda_b \hat{q}_3 \hat{d}_3^c \hat{h}_d$$

- Use R-symmetry so that $\lambda_b = 0$
- Then, $m_t \sim$ tree level
  $\sim$ EW scale
- m_b will be generated at 1-loop $\sim$few GeV

R charges:

$$\hat{q}_3, \hat{u}_3^c, \hat{e}_3^c \rightarrow 1$$
$$\hat{d}_3^c, \hat{l}_3, \hat{e}_3^c \rightarrow r$$
$$\hat{h}_u \hat{h}_d \rightarrow 0$$

With this assignment:

$$\hat{q}_3 \hat{u}_3^c \hat{h}_u : \text{allowed}$$
$$\hat{q}_3 \hat{d}_3^c \hat{h}_d : \text{forbidden}$$

Model & Formalism

How do we generate m_b, m_τ at 1-loop?

- Introduce vector-like quarks and leptons

$$(\hat{D}^c + \hat{\bar{D}}^c), (\hat{L} + \hat{\bar{L}})$$

R-charges $\hat{D}^c, \hat{\bar{D}}^c, \hat{L}, \hat{\bar{L}} \rightarrow 1$

Additional superpotential

$$W' = \lambda_D \hat{q}_3 \hat{D}^c \hat{h}_d + \lambda_L \hat{L} \hat{e}^c \hat{h}_d + M_D \hat{D}^c \hat{\bar{D}}^c + M_L \hat{L} \hat{\bar{L}}$$

Model & Formalism

- Generate μ-term, $B\mu$-terms and soft-SUSY breaking terms via higher-order operators

$$\int d^4\theta \frac{\hat{X}^\dagger}{M_{\rm Pl}} \hat{h}_u \hat{h}_d,\ \int d^4\theta \frac{\hat{X}^\dagger \hat{X}}{M_{\rm Pl}^2} \hat{h}_u \hat{h}_d,\ \int d^4\theta \frac{\hat{X}^\dagger \hat{X}}{M_{\rm Pl}} \hat{f}^\dagger \hat{f},$$
$$\int d^4\theta \frac{\hat{X}^\dagger \hat{Y}}{M_{\rm Pl}} \hat{D}^c \hat{d}_3^{c\dagger}, \quad \ldots$$

$X, Y \rightarrow$ spurion superfields

$$\langle X \rangle = M_{\rm Pl} + \theta^2 m M_{\rm Pl}$$
$$\langle Y \rangle = M_{\rm Pl} + \theta^2 m M_{\rm Pl}$$

R charges: $\begin{cases} X & \rightarrow 0 \\ Y & \rightarrow (r-1) \end{cases}$

$\Rightarrow$ Gives potential term

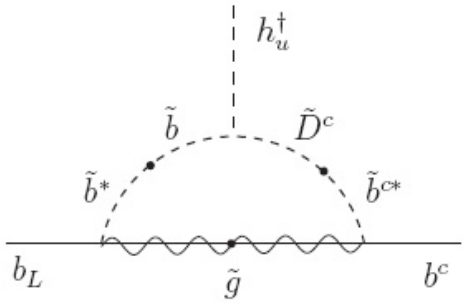
$$|F_{h_d}|^2 = |\lambda_D \tilde{q}_3 \tilde{D}^c + \lambda_L \tilde{L} \tilde{e}_3^c + \kappa\mu h_u|^2$$
$$\Rightarrow \mu\kappa(\lambda_D \tilde{q}_3 \tilde{D}^c h_u^\dagger + \lambda_L \tilde{L} \tilde{e}_3^c h_u^\dagger)$$

- Since SUSY is broken, the interactions

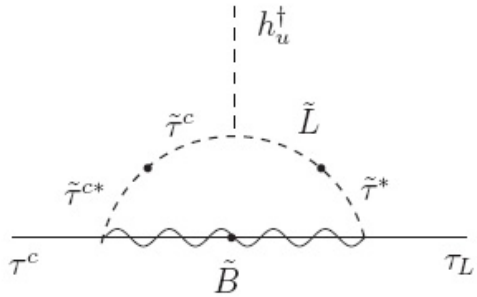
$$\lambda_b q_3 d_3^c h_u^\dagger, \quad \lambda_\tau l_3 e_3^c h_u^\dagger$$

are generated at the 1-loop level.

Model & Formalism



(a)



(b)

$\Rightarrow \lambda_b q_3 d_3^c h_u^\dagger$

$$\lambda_b = \frac{\lambda_D \alpha_3}{4\pi} \frac{8}{3} \mu \kappa m_{\tilde{g}} \frac{m_{dD}^2}{m_{\tilde{q}_3}^4} I_q$$

$$\lambda_\tau = \frac{\lambda_L \alpha_1}{4\pi} \frac{3}{5} \mu \kappa m_{\tilde{B}} \frac{m_{lL}^2}{m_{\tilde{e}_3^c}^4} I_l$$

$I_q, I_l \Rightarrow$ loop integrals

$\Rightarrow$ gives λ_b, λ_τ at the correct level

if the SUSY and vector-like quark and lepton masses are at $\sim$TeV

- Prediction $\Rightarrow$ vector-like quarks and leptons at TeV scale

Higgs Sector

- Three neutral Higgs (h, H, A)
  - lightest is h
- charged Higgs $(H^{\pm})$

$$\mathcal{L}_{f_3 f_3 \phi} = \frac{m_t}{\sqrt{2} v s_\beta} \left[\bar{t} t (c_\alpha h + s_\alpha H) + \bar{t} i \gamma_5 t c_\beta A \right]$$
$$+ \text{ bottom terms } + \text{ tau terms}$$

$$\mathcal{L}_{f_3 f_3 H^{\pm}} = \frac{m_t}{v \tan\beta} b_L t^c H^+ + \text{ h.c. } + \text{ tau terms}$$

For $m_{H,A,H^{\pm}} \gg m_h, m_Z$; $\lambda_{\bar{t}th}, \lambda_{\bar{b}bh}, \lambda_{\bar{\tau}\tau h} \Rightarrow$ SM couplings.
Whereas $H, A, H^{\pm}$ coupling to fermions $\Rightarrow \frac{m_f}{\sqrt{2}v}\left(\frac{1}{\tan\beta}\right) \to 0$ for large $\tan(\beta)$.

Gauge Couplings for Higgs

$$g_{H\to VV} \sim \frac{g}{2}\frac{m_h^2}{M_H^2}$$

- *Heavy Higgs sector ∼decouples from both gauge and fermion sector*

  $\Rightarrow$*fermiophobic heavy Higgs sector (FMSSM)*

Phenomenological Implications

(A)LHC Signals

- New vector-like quarks, $D^c, \overline{D}^c$ and leptons $L, \overline{L}$ at the TeV scale.
- $D^c, \overline{D}^c$ can be produced at LHC, $\sigma(M_D \sim 1\mathrm{TeV}) \sim 100\mathrm{fb}$
- Decays: $D^c \to Hb, H^{\pm}t$ dominant
  $D^c \to hb$ suppressed

Pnomenological Implications

(1) If $M_H > M_{D^c}$, then $D^c \rightarrow hb$

$\Rightarrow hhb\bar{b}$ *(double Higgs productions with anomalous large cross section)*

(2) If $M_H < M_{D^c}$

Then $D^c \rightarrow bH,\ tW$
Signal $\Rightarrow b\bar{b}4W, b\bar{b}4Z,\ b\bar{b}t\bar{t}$
$\Rightarrow$ *observable signal at the early run at LHC*

Phenomenological Implications

(B) Difference with usual MSSM

- No enhancement for the rare processes

$$\text{like } b \to s\gamma,\ B_0 \to \mu^+\mu^-$$

($b\bar{b}$, $\tau\bar{\tau}$ couplings not $\tan\beta$ enchanced)

(C) Different SUSY signals

- $f\tilde{f}h$ coupling insensitive to $\tan\beta$
  $\Rightarrow$extend the DM region.

(D) $(\hat{D}^c + \hat{\bar{D}}^c), (\hat{L} + \hat{\bar{L}}) \Rightarrow$ complete multiplet
$\Rightarrow$ gauge coupling unification *not* affected

Inclusion of Light Families

- Introduce: $(\hat{D}^c + \hat{\bar{D}}^c)_i, (\hat{L} + \hat{\bar{L}})_i \; i = 1, 2, 3$
  - Fermion mass hierarchy and CKM can be accommodated
  - FCNC avoided using appropriate flavor symmetry (ex. $SO(3)$)

Embedding in $SU(5)$ GUT

- For one family $10 + \bar{5}$

$$(q, u^c, e^c) + (d^c, l)$$

- Add vectorlike $F + \bar{F}$ in TeV scale

$$(D^c, L) + (\bar{D}^c, \bar{L})$$

$\Rightarrow m_b, m_\tau$ masses generated radiatively
$\Rightarrow$can give miss-match from $m_b = m_\tau$
$\Rightarrow$fermion mass relations (to be studied)

Conclusions

- We proposed a new extension of MSSM
  $\Rightarrow$ FMSSM
- Realized using suitable R-symmetry
- Preserve the goodies of MSSM, but testable differences tan β dependence, $b \to s\gamma$, $B_0 \to \mu^+\mu^-$, may extend the allowed DM region
- Requires vector-like quarks $D^c + \bar{D}^c$, $L + \bar{L}$ at $\sim$1 TeV
- Lightest neutral CP even Higgs h essentially SM like
- Heavy Higgs sector fermiophobic (FMSSM)
- Interesting new signals at the LHC from the pair production of $D^c, \bar{D}^c$
  $\Rightarrow b\bar{b}4W, b\bar{b}4Z, b\bar{b}t\bar{t}, b\bar{b}hh$
- Could be observed at the early runs at the LHC