A realization of effective supersymmetry with Strong unification

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[1] C. L., $[SU(3)\times SU(2)\times U(1)]^2$ and strong unification, Phys. Lett. B591 (2004) 137.

[2] C. L. & Zhen-Hua Zhao, to appear

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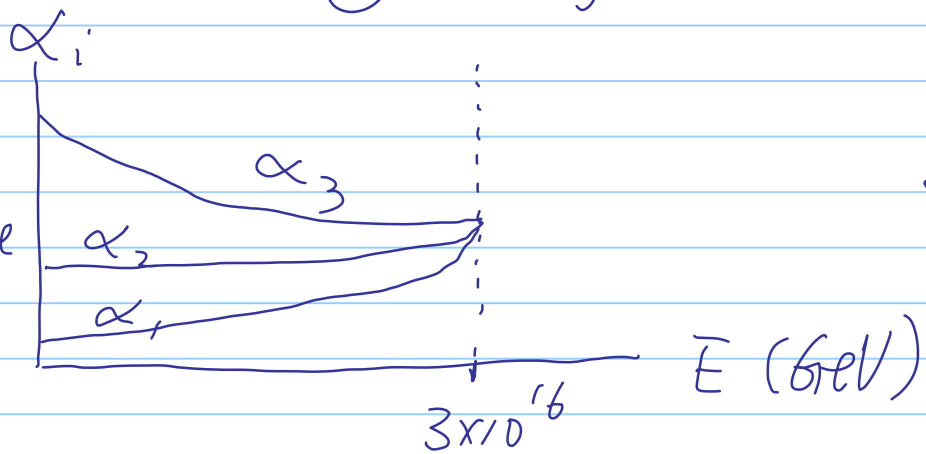
Backup

- effective SUSY (A.G. Cohen, Kaplan, Nelson, 96)
  for SUSY FCNC

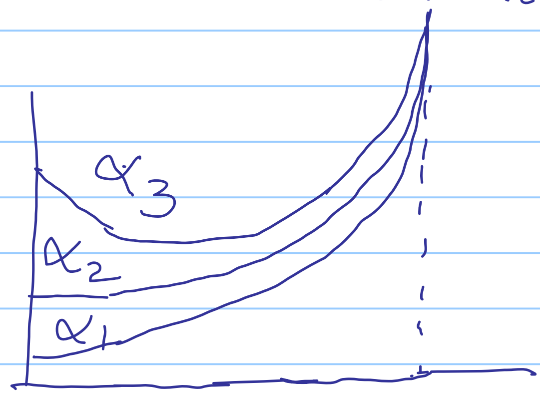
{ 1st & 2nd generation sfermions superheavy $\sim (10-100)$ TeV
{ 3rd generation sfermions $\sim$ 100 GeV – 1 TeV

- strong unification (Maiani; Parisi; Petronzio, 78)

Perturbative



Strong



MSSM

common Landau pole

ratios of gauge couplings are infra-fixed point

$\alpha_s^{exp}(M_Z) \simeq 0.118 \pm 0.002$

$\alpha_s^{MSSM}(M_Z) \simeq 0.126$

?

For example, strong GUT w/ new matters

$\left\{ \begin{array}{l} 214 \text{ TeV} \\ \text{six } 5 \oplus \bar{5} \text{ multiplets} \end{array} \right.$

$\Rightarrow \alpha_s(M_Z) \simeq 0.1163$

see, C. L. (2004)

1. Introduction

Current experimental status,

Standard Model correct !!! $m_h \simeq 126$ GeV

No SUSY signals yet

- A light Higgs is not inconsistent w/ SUSY
- grand unification $\begin{cases} \text{family structure} \\ \text{gauge coupling constants} \end{cases}$

So, we still want GUT with TeV SUSY

LHC constraints : $\begin{cases} m_{\tilde{Q}_1}, m_{\tilde{Q}_2} > 1\,\text{TeV} \\ m_{\tilde{Q}_3} > 500\,\text{GeV} \end{cases}$

effective SUSY o.k.

Basic idea

$$SU(3)_1 \times SU(2)_1 \times U(1)_1 \times SU(3)_2 \times SU(2)_2 \times U(1)_2$$

$$\Downarrow \quad \leftarrow \text{Higgs (new matter)}$$

$$SU(3)_c \times SU(2)_L \times U(1)_Y \qquad \text{(SM)}$$

1st & 2nd generations are in $SU(3)_1 \times SU(2)_1 \times U(1)_1$ – strong

3rd generation is in $SU(3)_2 \times SU(2)_2 \times U(1)_2$ – weak

gauge mediated susy breaking $\Rightarrow$

$$m_{\tilde{Q}_1} \sim m_{\tilde{Q}_2} \sim 10 - 100 \text{ TeV}$$

$$m_{\tilde{Q}_3} \sim 1 \text{ TeV}$$

II. The model

SUSY $G_1 \times G_2$

where $G_i = SU(3)_i \times SU(2)_i \times U(1)_i$

gauge mediated SUSY breaking

$G_1 \times G_2$ --- messengers --- ~~SUSY~~

G_1 — strong @ TeV, G_2 — weak @ TeV

⇑ ⇑

1st & 2nd generation 3rd generation

4 H_u, H_d

Sometimes we use global $SU(5)_i \supset G_i$

2.1 Susy breaking

X — chiral superfield

$\langle X_s \rangle \neq 0 \qquad \langle F_X \rangle \neq 0$

2.2. GMSB

messengers $\quad T_1 (G_1, 1), \ \bar{T}_1 (\bar{G}_1, 1)$

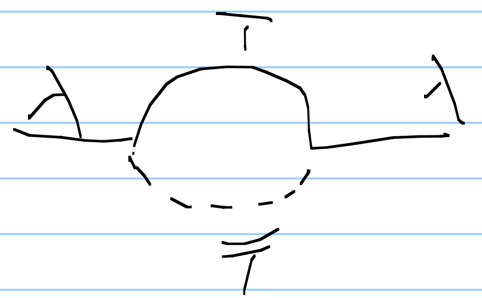
$T_2 (1, G_2), \ \bar{T}_2 (1, \bar{G}_2)$

$$W_{GMSB} = (c_1 T_1 \bar{T}_1 + c_2 T_2 \bar{T}_2) \cdot X$$

messenger masses $\quad$ Dirac fermions $\quad c_i \langle X_s \rangle$

Bosons $\begin{cases} c_i^2 \langle X_s \rangle^2 + c_i \langle F_X \rangle \\ c_i \langle X_s \rangle^2 - c_i \langle F_X \rangle \end{cases}$

$G_1 \times G_2$ sector



G_2 gauginos: $M_{\lambda'} \simeq \frac{\alpha'}{4\pi} \frac{\langle F_X \rangle}{\langle X_S \rangle}$

$M^2_{\tilde{Q}_3} \simeq \left(\frac{\alpha'}{4\pi} \frac{\langle F_X \rangle}{\langle X_S \rangle} \right)^2$

G_1 gaugino: $M_\lambda \simeq \frac{\langle F_X \rangle}{\langle X_S \rangle}$

$M^2_{\tilde{Q}_{1,2}} \simeq \left(\frac{\langle F_X \rangle}{\langle X_S \rangle} \right)^2 \sim (10\text{-}100\,\text{TeV})^2$

2.3 Gauge symmetry breaking

Higgs $\Phi_1\ (5,\bar{5})$, $\Phi_2\ (\bar{5},5)$

$$G_1 \times G_2 \longrightarrow SM$$

$$W \supset c' Y \left[Tr(\Phi_1 \Phi_2) - \mu'^2 \right] + c_2' Tr(\Phi_2 A \Phi_1)$$

write $\langle \phi_{1s} \rangle = v_1\, I_3 \otimes I_2$, $\langle \phi_{2s} \rangle = v_2\, I_3 \otimes I_2$

where I_3 – unit matrix in $SU(3)_1 \times SU(3)_2$

I_2 – unit matrix in $SU(2)_1 \times SU(2)_2$

scalar potential

$$V = \left| c'(3 v_1 v_2 - \mu'^2) \right|^2 + \frac{g_1^2 + g_1'^2}{2} (v_1^2 - v_2^2)$$

$$\Rightarrow \quad v_1 = v_2 = \frac{1}{\sqrt{3}} u' \quad - \quad u_{\Phi}$$

$$\frac{1}{g_5^2} = \frac{1}{g_3^2} + \frac{1}{g_3'^2} , \quad \frac{1}{g^2} = \frac{1}{g_2^2} + \frac{1}{g_2'^2} , \quad \frac{1}{g'^2} = \frac{1}{g_1^2} + \frac{1}{g_1'^2}$$

III. Yukawa interactions

3rd generation is in G_2
1st and 2nd are in G_1 ?

In G_2, we further introduce an extra vector-like generation $(L, \bar{d})$ and $(Q, \bar{u}, \bar{e})$ as $\bar{5} \oplus 10$

mass — M_Ψ

Look at down-type quarks, we have

$$y_{3d} H_d Q_3 \bar{d} + M_\Psi d\bar{d} + y_{d_{1(2)}} \bar{d}_{1(2)} \Phi_{d\bar{d}}\, d$$

where $\Phi_{d\bar{d}}$ is the component of the Higgs Φ with $(3,1,-\frac{1}{3}) \times (\bar{3},1,\frac{1}{3})$

integrating heavy $d(\bar{d})$ and $\Phi_{d\bar{d}}$,

$$\Longrightarrow \frac{V}{M_4} H_d Q_3 \bar{d}_{1(2)}$$

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IV. EWSB

It occurs like that in the MSSM,

$$m_h^2 = m_Z^2 \cos^2 2\beta + \frac{3m_t^4}{4\pi^2 v^2}\left[\log\frac{m_{\tilde{t}}^2}{m_t^2} + \frac{X_t^2}{m_{\tilde{t}}^2}\left(1 - \frac{X_t^2}{12m_{\tilde{t}}^2}\right)\right]$$

where $X_t = A_t - \mu\cot\beta$

$m_h \simeq 126$ GeV is a trouble for ordinary GMSB

We need a large A-term,

make use of an observation of Kang et al.,

choosing messengers T_2 ($\bar{T}_2$) as 10 ($\bar{10}$),

and introducing direct interaction between

EW Higgs and messengers,

$y H_u T_2^{Q} T_2^{\bar{u}}$ — the only allowed term w/ messenger parity

T_2^{Q}, $T_2^{\bar{u}}$ are components of T_2 that have same quantum numbers as Q_3 and $\bar{u}_3$

$$A_t \sim \frac{y^2}{16\pi^2} \frac{\langle F_X \rangle}{\langle X_S \rangle}$$

Backup

- $A - m_h^2$ problem in GMSB

~~SUSY~~ : $X = \langle X_S \rangle + \langle F_X \rangle \theta\theta$

A-term after integrating out messengers,

$$\frac{C_A}{M} X H^\dagger_{u,d} H_{u,d} \Big|_{\theta\theta\bar{\theta}\bar{\theta}} \quad \text{with } F^\dagger_{H_{u,d}} \rightarrow -y_u Q\bar{u}$$

o.k

But, $\frac{c_A}{M^2} X^\dagger X H_{u,d}^\dagger H_{u,d} \Rightarrow m_h^2 \simeq A_t^2 \times 1000$?

How to avoid this problem?

$$W = \lambda T \bar{T} X + \cancel{M T \bar{T}}$$
$$+ y H_u T \bar{T} + H_d T \bar{T}$$

will be o.k.

Integrating T ($\bar{T}$), the effective Kahler:

$$K_{eff} \supset Z_u(X X^\dagger) H_u^\dagger H_u + Z_d(X, X^\dagger) H_d^\dagger H_d + \cdots$$

$$A_{u,d} = F_X \partial_X Z_{u,d}, \quad m_{H_{u,d}}^2 = |F|^2 \partial_X \partial_{X^\dagger} Z_{u,d}$$

look at W, there is R-symmetry,

$$R(T) = R(\bar{T}) = 0, \quad R(H_u) = R(H_d) = R(X) = 2$$

$$Z^{(1)}_{u,d} = \underbrace{c\,\lambda^2}_{\text{one-loop factor}} \log \frac{X^+ X}{\Lambda_0^2}$$

$$\Rightarrow m_h^2 = 0$$

V. strong unification

many matter fields introduced

$g_i' \nearrow$ at high energies

$g_i \gg g_i' \Rightarrow$ observed unification of the MSSM is attributed to that of G_2

For G_2: matter fields are

- 3rd generation
- H_u, H_d

$\Phi_1 \ (\bar{\Phi}_2)$, $5 \times \bar{5}$ $(\bar{5} \times 5)$, M_Φ

$T_2 \ (\bar{T}_2)$, 10 $(\overline{10})$, M

a vector-like generation, $5 + \overline{10}$ $(\bar{5} + 10)$, M_4

In the analysis, we take

$$M \sim M_\Phi \sim M_4$$

and also consider a finite g_i / g_i',

We have $M \sim 10^7$ GeV,

$\alpha_s(M_Z) \simeq 0.116$, $m_{\tilde{\alpha}_{1,2}} \simeq 20$ TeV, $m_{\tilde{\alpha}_3} \simeq 1$ TeV

VI. Summary

If SUSY is relevant to EW physics, we expect an effective SUSY spectrum will be found @ LHC

We realize effective SUSY via a SUSY $SU(3)\times SU(2)\times U(1)\times SU(3)\times SU(2)\times U(1)$ with gauge mediated SUSY breaking

Thanks !