Underlying Gauge Symmetry and Dim.-4 Proton Decay

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SUSY SU(5) Unification

Interactions in N=1 SUSY

gauge coupling: unification

Yukawa coupling: mess

In N = 4 Super Yang—Mills theories,
Yukawa coupling is a part of the N = 4 super Yang—Mills.

string pheno: translate the hierarchy and mixing patterns into geometry
better understanding, justifying phen. approaches, extra information or ....?
Underlying Gauge Symmetry: I

- What is $G$?
  - What / Who we ($q, l, g, \gamma, ...$) are
  - What is Higgs, what are right-handed neutrinos?

- [Top Down] seems arbitrary in current string theory.
  - D-branes, ADE singularities (string junction), ......

- [Bottom Up and Top Down combined] better prospect.
Underlying Gauge Symmetry: II

Lykken, Poppitz, Trivedi '98

\[ G = SO(11) \text{ in Type IIB or Type I, } C^{1/2}, \text{ or } T^{1/2}. \]

\[ H = SU(5) \]

\[
\begin{array}{c|c|c}
\text{adj.} & 10 & 5 \\
\hline
70 & 5
\end{array}
\]

\[ 3 \text{ chiral multiplets of } (10 + \overline{5}) \]  

\[ W = E_{abc} \text{ tr}_{SO(11)-\text{adj.}} (Z^a (\partial - Z^b) Z^c) \]

\[ \rightarrow W = 5^a 10_b 5^c E_{abc}. \text{ Dim. } -4 \text{ pdecay.} \]

Lie algebra of G tells us what kind of interactions may be generated.
What is $G$?

[in Heterotic string language] turn on $\text{SU}(2) \times \text{U}(1)$ vect. bndl. to break $G$ to $H$, and to generate chirality in $D = 4$ theory.

Down-type Yukawa coupling is not generated from the $E_6$ super YM.

$G = E_7$ or $E_8$. 
Minimal Choice $E_7$

$$\text{Res}_{SU(5)_{\text{aut}} \times SU(2)}^{E_7}$$

$$e_7 - \text{adj.} = (\text{adj.} \cdot 1) + (1 \cdot \text{adj.})$$

\[
\begin{align*}
&\left[ + \frac{(5, 1)}{6} \right. \\
&+ \left( \frac{(5^2, 2)}{4} \right) + \left( \frac{(A^5, 2)}{2} \right) + \left( \frac{(10, 1)}{6} \right) \\
&+ \left( \frac{(5, 2)}{2} \right) + \left( \frac{(10, 1)}{6} \right) + h.c. \\
&\left. + \left( \frac{(1, 2)}{2} \right) \right]
\end{align*}
\]

$$W \rightarrow (\lambda^5, 2) \otimes (\lambda^5, 2) \otimes (\lambda^5, 1) \rightarrow 10 \cdot 10 \cdot H(5),$$

$$\rightarrow 5 \cdot 10 \cdot H(5), \quad \text{H.H.} 105$$

$$\rightarrow H(5) \cdot 5 \cdot N, \quad \text{H.H.} 5$$

**Proton Decay Operators**

- Dim. = 4
  $$\frac{(5, 2)}{2} \otimes (\lambda^5, 2) \otimes (\lambda^5, 2)$$

- Dim. = 5
  $$\frac{(5, 2)}{2} \otimes (\lambda^5, 2) \otimes (\lambda^5, 2)$$

$G = E_7$ is the minimal choice.

$E_8$ is not necessary.
Dim.-4 Proton Decay Operators

\[ E_8 \quad \text{w/ SU}(5) \text{ bdle. } V_5 \]

\[ W = (10, V_5) \otimes (10, V_5) \otimes (H(5), \wedge^2 V_5) \]
\[ + (\bar{5}, \wedge^2 V_5) \otimes (10, V_5) \otimes (\bar{H}(\bar{5}), \wedge^2 V_5) \]
\[ + (\bar{5}, \wedge^2 V_5) \otimes (N, \text{ad.}(V_5)) \otimes (H(5), \wedge^2 V_5) \]

\[ \bar{5}, \bar{H}(\bar{5}) \in H^1(Z, \wedge^2 V_5), \quad H(5) \in H^1(Z, \wedge^2 V_5). \]

If there is not distinction between $\bar{5}$ and $\bar{H}(\bar{5})$, dim.-4 proton decay operators are also generated.

\[ W = (\bar{5}, \wedge^2 V_5) \otimes (10, V_5) \otimes (\bar{5}, \wedge^2 V_5) \]
\[ = \overline{DUDD} + \overline{DQL} + \overline{LEL}. \]
How to Kill Them?

$Z_2$ symmetry (matter / R parity) in \((CY_3, Z, \text{bdle. } V_5)\)

$$\bar{5} \in H^1(Z, \wedge^2 V_5)^-, \quad \overline{H(5)} \in H^1(Z, \wedge^2 V_5)^+.$$

Reducible vector bundle

\[
V_5 = L \oplus U_4, \quad \text{with} \quad L \otimes \det U_4 \simeq \mathcal{O}_Z,
\]

$$\bar{5} = (\bar{D}, L) \quad \text{from} \quad H^1(Z; U_4 \otimes L)$$

$$\overline{H(5)} \quad \text{from} \quad H^1(Z; \wedge^2 U_4)$$

d, e – Yukawa:

\[
(U_4 \otimes L) \otimes U_4 \otimes (\wedge^2 U_4) \Rightarrow \wedge^4 U_4 \otimes L,
\]

p decay:

\[
(U_4 \otimes L) \otimes U_4 \otimes (U_4 \otimes L) \Rightarrow \wedge^3 U_4 \otimes \wedge^2 L.
\]
The structure group is SU(4) x U(1), and the U(1) symmetry is not broken by the bdle configuration. This is the B – L symmetry; its gauge boson has mass terms through Green-Schwarz mechanism.

\[ \mathcal{L} = \frac{1}{2g_{YM}^2} 2 \text{tr} f(q_x^2) D_x^2 + D_x \xi_x + D_x q_x i \psi_i^\dagger \psi_i \rightarrow V = \frac{1}{2} \frac{g_{YM}^2}{2 \text{tr} f(q_x^2)} (\xi_x + q_x i \psi_i^\dagger \psi_i)^2 \]

\[ \xi_x = \frac{10M_C^2}{32\pi^2} \left[ \frac{2\pi l_s^2}{\text{vol}(Z)} \int c_1(L) \wedge J \wedge J - \frac{g_{YM}^2 e^{2\phi_4}}{2} \int c_1(L) \left( c_2(V_5) - \frac{1}{2} c_2(TZ) \right) \right] \]

Kahler moduli dilaton

The Fayet—Iliopoulos parameter may not vanish.

Blumenhagen, Honecker, Weigand ‘05
If \( \xi < 0 \),

the D-term condition (equation of motion of the gauge field)

\[
\xi - 5|\overline{N}|^2 + 5|\overline{\overline{N}}|^2 - |10|^2 + 3|5|^2 + 2|H|^2 - 2|\overline{H}|^2 = 0
\]

can be satisfied by \( \langle \overline{N} \rangle \neq 0, \langle \overline{\overline{N}} \rangle = 0 \).

This is equivalent to \( 0 \rightarrow L \rightarrow V_5 \rightarrow U_4 \rightarrow 0 \).

more general than the reducible bdle’s.

Broken B – L symmetry allows Majorana RH neutrino masses, and consequently the see-saw mechanism to work.

cf. Dine Seiberg Wen Witten ‘86
Beasley Witten ‘03
SUSY-zero mechanism

\[ \langle \bar{N} \rangle \neq 0. \quad \text{R-parity is broken, but...} \]

The underlying \( G = E_8 \) gauge symmetry does not allow

\[ W \neq 5 \cdot 10 \cdot 5 \cdot \langle \bar{N} \rangle^{n \geq 0}. \]

Operators of the form \( W = 5 \cdot 10 \cdot 5 \cdot \langle \bar{N} \rangle \) is allowed,

they are not dangerous as long as \( \langle \bar{N} \rangle = 0. \)

This can be regarded as the SUSY-zero mechanism

of B-L U(1) gauge symmetry.
Integrating out heavy states, R-parity violating operators are generated.

The LSP is not stable.

LSP decay may be seen in future collider experiments

no longer a good candidate for dark matter

Axion dark matter?
Summary

- Yukawa couplings from super YM in SU(5) GUT
  - $G = E_7$ or $E_8$.
- An alternative idea to R parity
  - vector bundles given by extension
  - massless modes from the right “sub-bundles”
- Roughly speaking, that’s SUSY-zero mechanism.
- LSP decay, possibly axion dark matter.