Underlying Gauge Symmetry and Dim.-4 Proton Decay

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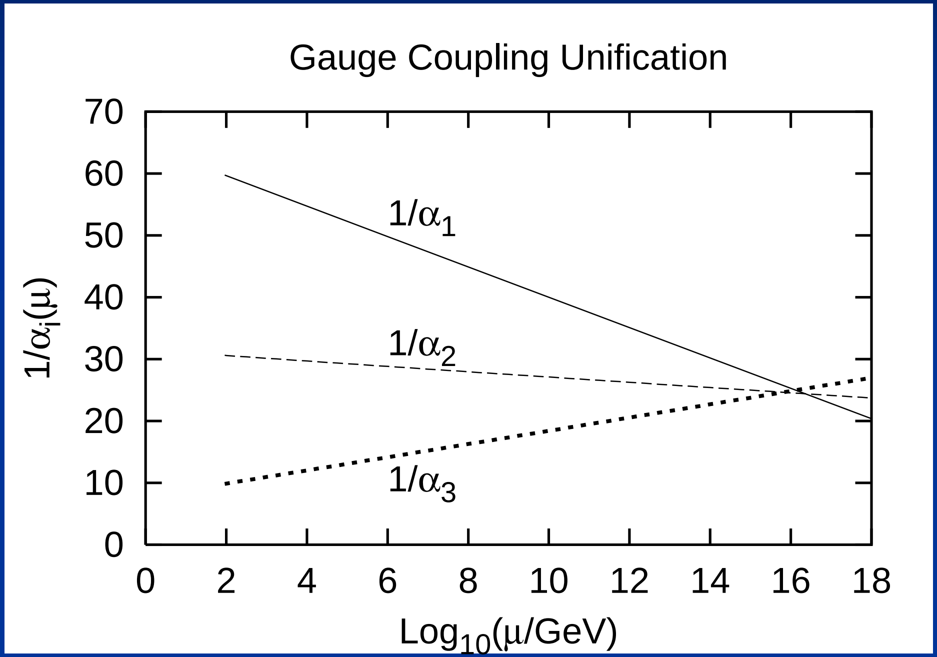
Taizan Watari (UC Berkeley)
collaboration w/ Radu Tatar (Liverpool)

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.

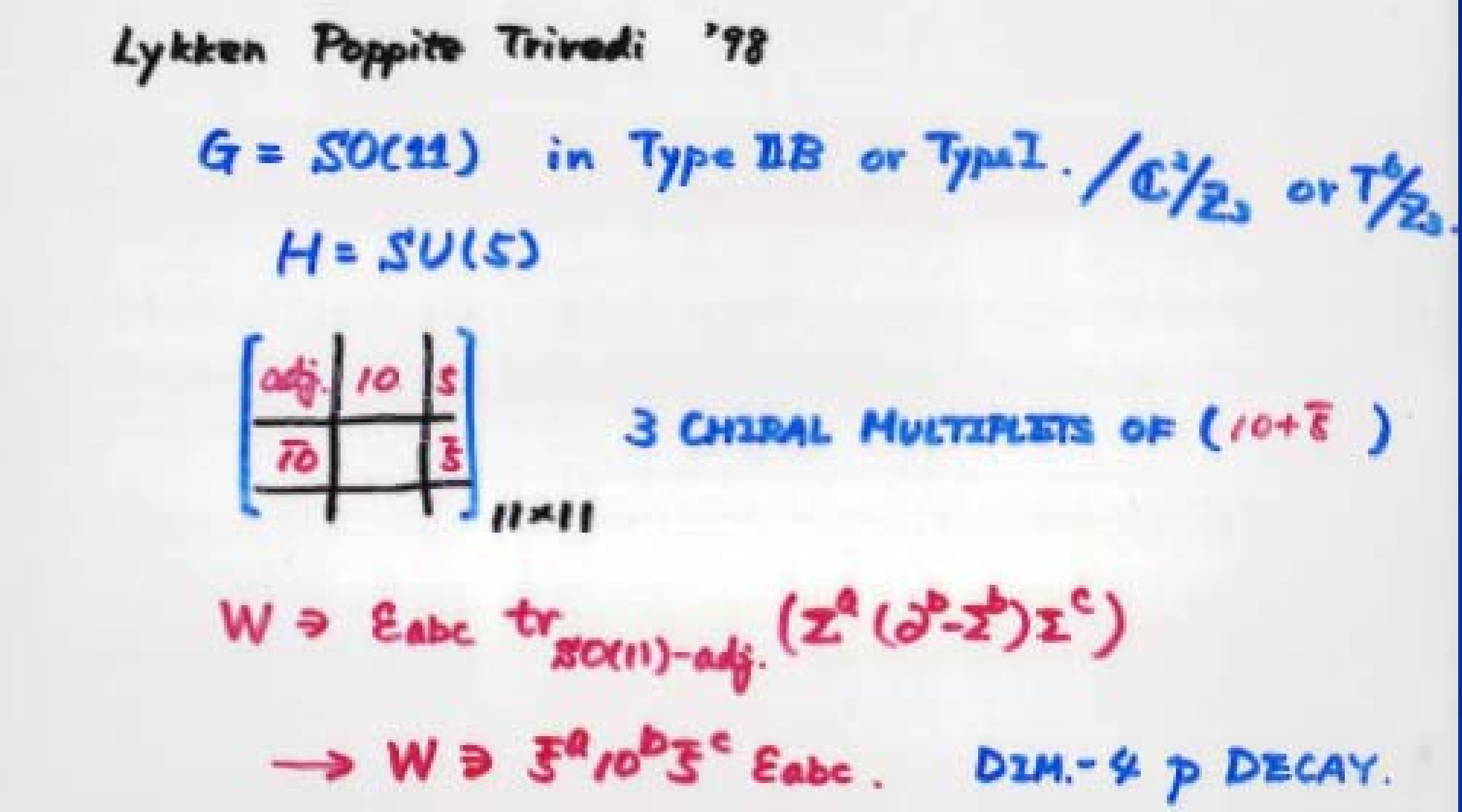
string pheno: translate the hierarchy and mixing patterns into geometry

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

$G = SO(11)$ in Type IIB or Type I $/\mathbb{C}^3/Z_3$ or T^6/Z_3.

$H = SU(5)$

$$\left[\begin{array}{c|c|c} \text{adj.} & 10 & 5 \\ \hline \overline{10} & & \bar{5} \\ \hline \end{array}\right]_{11\times 11}$$

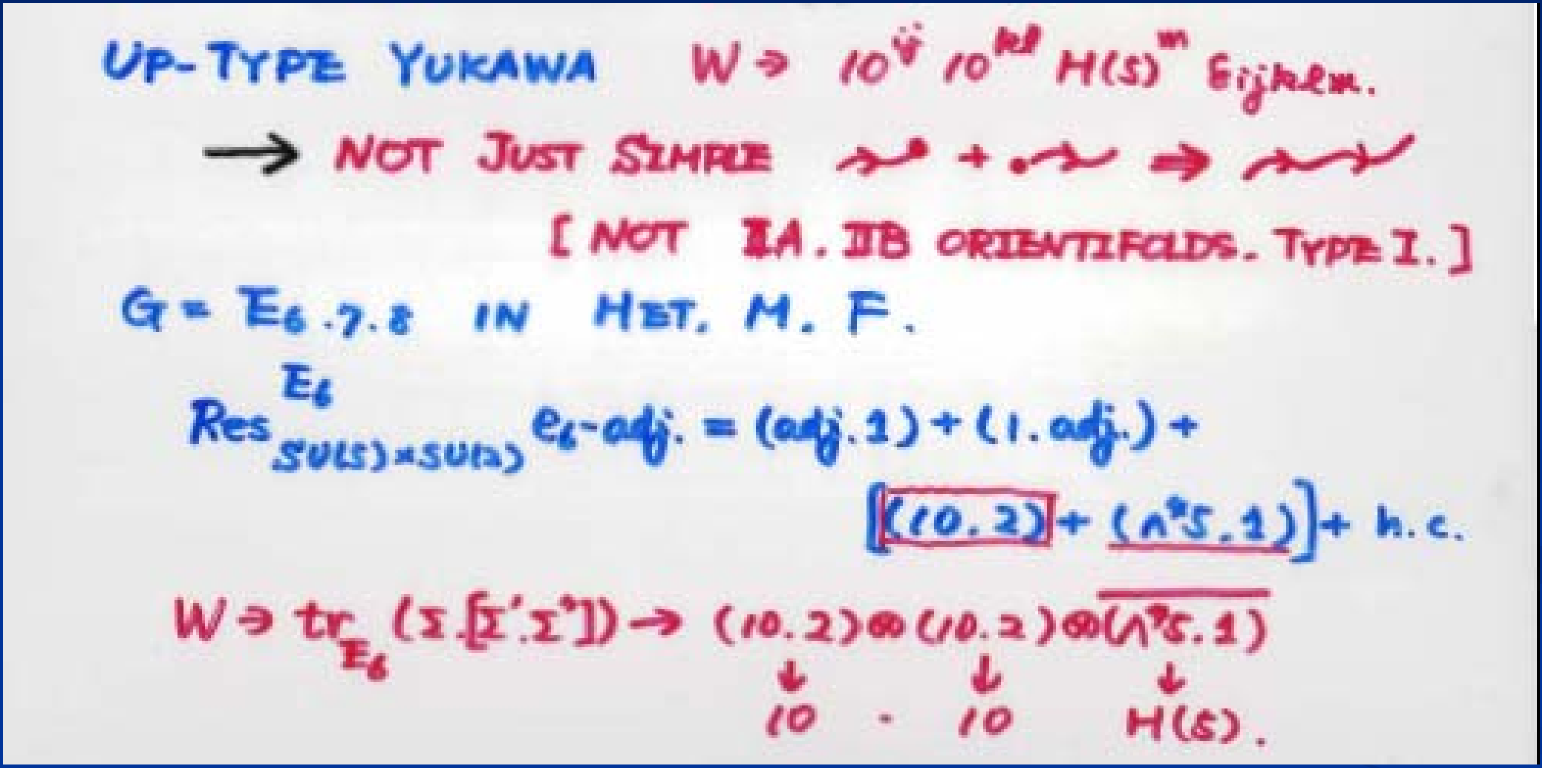
3 CHIRAL MULTIPLETS OF $(10+\bar{5})$

$$W \ni \varepsilon_{abc}\, \mathrm{tr}_{SO(11)\text{-adj.}}\left(\Sigma^a(\partial^b - \Sigma^b)\Sigma^c\right)$$

$$\longrightarrow W \ni \bar{5}^a 10^b \bar{5}^c \varepsilon_{abc}.$$ DIM.-4 p DECAY.

Lie algebra of G tells us what kind of interactions may be generated.

What is G ?



UP-TYPE YUKAWA $W \ni 10^{ij}\, 10^{kl}\, H(5)^{m}\, \epsilon_{ijklm}$.

→ NOT JUST SIMPLE

[NOT IIA. IIB ORIENTIFOLDS. TYPE I.]

$G = E_{6.7.8}$ IN HET. M. F.

$$\mathrm{Res}^{E_6}_{SU(5)\times SU(2)}\, e_6\text{-adj.} = (\text{adj}.1) + (1.\text{adj}.) + \left[\boxed{(10.2)} + \underline{(\wedge^3 5.1)}\right] + \text{h.c.}$$

$$W \ni \mathrm{tr}_{E_6}(\Sigma[\Sigma'.\Sigma'']) \to \underset{\substack{\downarrow \\ 10}}{(10.2)} \otimes \underset{\substack{\downarrow \\ 10}}{(10.2)} \otimes \underset{\substack{\downarrow \\ H(5)}}{\overline{(\wedge^3 5.1)}}$$

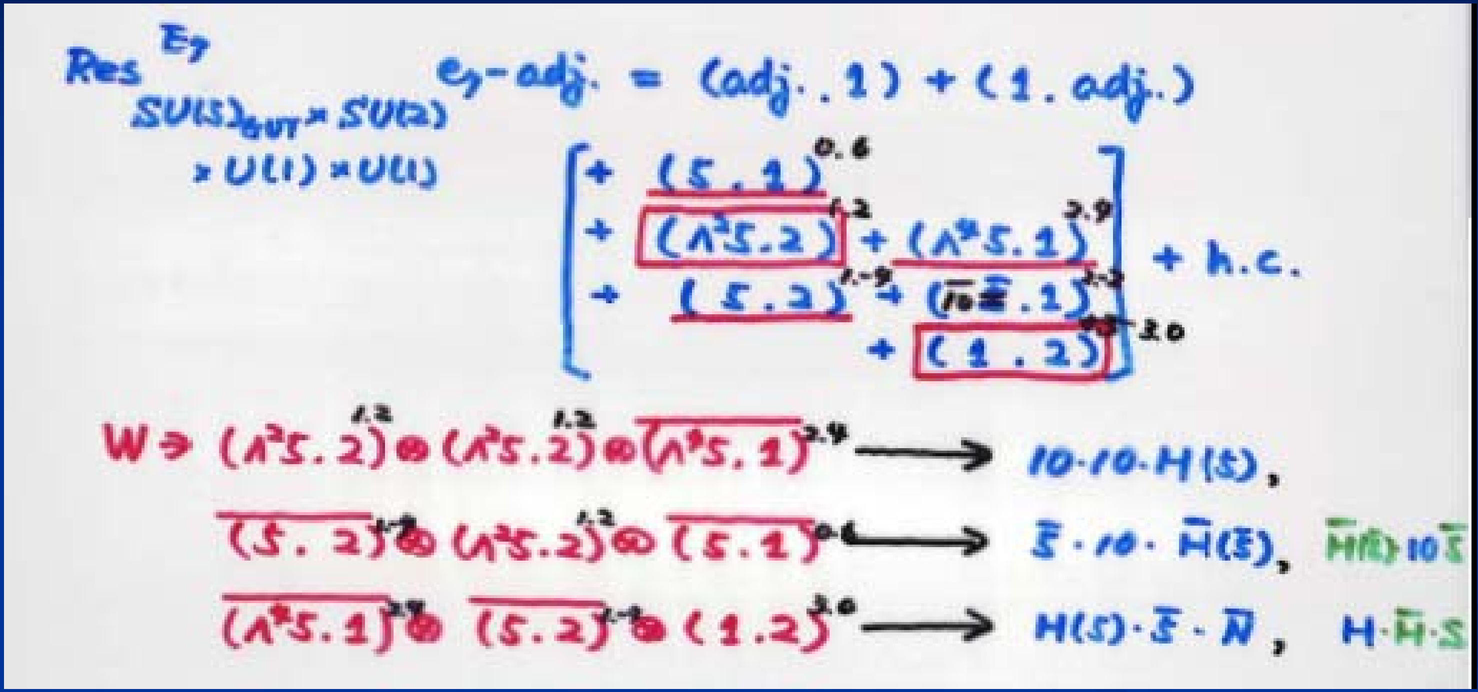
$10 \cdot 10 \quad H(5)$.

[in Heterotic string language] turn on SU(2) x 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



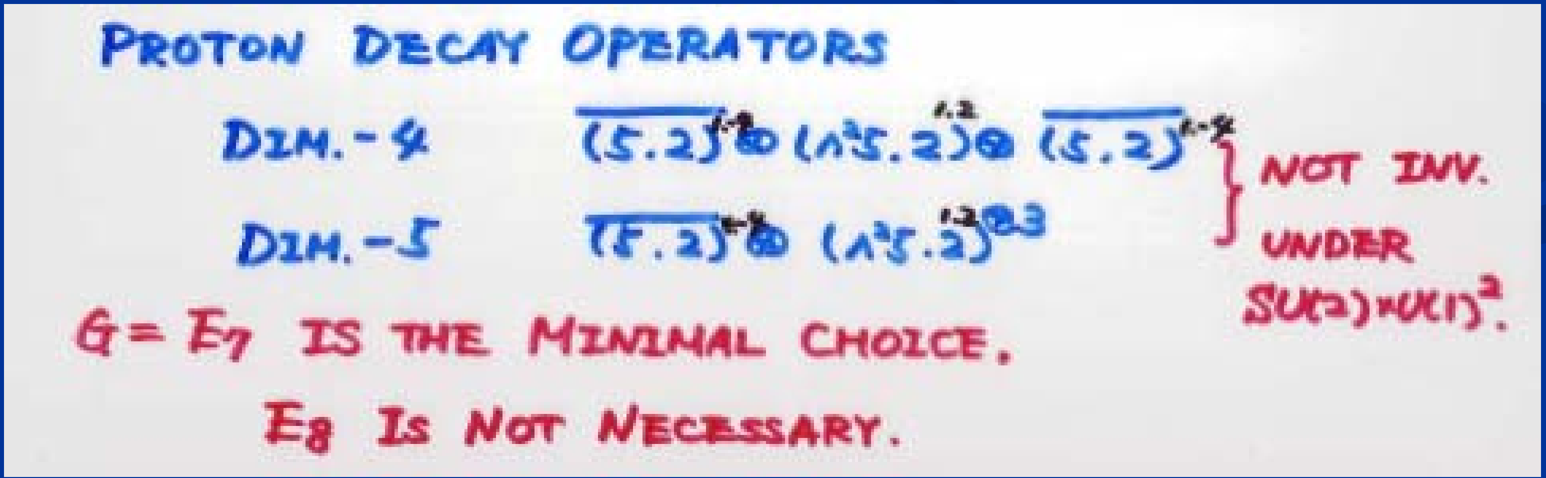
$$\mathrm{Res}^{E_7}_{SU(5)_{GUT}\times SU(2)\times U(1)\times U(1)}\ e_7\text{-adj.} = (\text{adj.}\,.\,1) + (1\,.\,\text{adj.})$$

$$\left[\begin{array}{l} +\ \underline{(5\,.\,1)}^{0.6} \\ +\ \boxed{(\Lambda^2 5\,.\,2)}^{1.2} + \underline{(\Lambda^4 5\,.\,1)}^{2.4} \\ +\ \underline{(5\,.\,2)}^{1.-4} + (\overline{10}\,\bar{5}\,.\,1)^{2.-2} \\ \qquad\qquad + \boxed{(1\,.\,2)}^{3.0} \end{array}\right] + \text{h.c.}$$

$$W \ni (\Lambda^2 5\,.\,2)^{1.2} \otimes (\Lambda^2 5\,.\,2)^{1.2} \otimes \overline{(\Lambda^4 5\,.\,1)^{2.4}} \longrightarrow 10\cdot 10\cdot H(5),$$

$$\overline{(5\,.\,2)^{1.-4}} \otimes (\Lambda^2 5\,.\,2)^{1.2} \otimes \overline{(5\,.\,1)^{0.6}} \longrightarrow \bar{5}\cdot 10\cdot \bar{H}(\bar{5}), \quad \bar{H}(\bar{5})\,10\,\bar{5}$$

$$\overline{(\Lambda^4 5\,.\,1)^{2.4}} \otimes \overline{(5\,.\,2)^{1.-4}} \otimes (1\,.\,2)^{3.0} \longrightarrow H(5)\cdot\bar{5}\cdot\bar{N}, \quad H\cdot\bar{H}\cdot S$$



PROTON DECAY OPERATORS

$$\left.\begin{array}{ll} \text{DIM.-4} & \overline{(5\,.\,2)^{1.-4}} \otimes (\Lambda^2 5\,.\,2)^{1.2} \otimes \overline{(5\,.\,2)^{1.-4}} \\ \text{DIM.-5} & \overline{(5\,.\,2)^{1.-4}} \otimes \left((\Lambda^2 5\,.\,2)^{1.2}\right)^{\otimes 3} \end{array}\right\} \begin{array}{l}\text{NOT INV.} \\ \text{UNDER} \\ SU(2)\times U(1)^2. \end{array}$$

$G = E_7$ IS THE MINIMAL CHOICE.

E_8 IS NOT NECESSARY.

Dim.-4 Proton Decay Operators

E_8 w/ SU(5) bdle. V_5

$$W = (10, V_5) \otimes (10, V_5) \otimes (H(5), \overline{\wedge^2 V_5})$$ u-Yukawa

$$+ (\bar{5}, \wedge^2 V_5) \otimes (10, V_5) \otimes (\overline{H}(\bar{5}), \wedge^2 V_5)$$ d,e-Yukawa

$$+ (\bar{5}, \wedge^2 V_5) \otimes (\overline{N}, \mathrm{ad.}(V_5)) \otimes (H(5), \overline{\wedge^2 V_5})$$ neutrino Yukawa

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

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

$$W = (\bar{5}, \wedge^2 V_5) \otimes (10, V_5) \otimes (\bar{5}, \wedge^2 V_5)$$

$$= \overline{D}\overline{U}\overline{D} + \overline{D}QL + L\overline{E}L.$$

How to Kill Them ?

Z_2 **symmetry** (matter / R parity) in $(\mathrm{CY}_3\ Z, \mathrm{bdle.}\, V_5)$

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

Reducible vector bundle

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

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

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

d, e –Yukawa : $(U_4 \otimes L) \otimes U_4 \otimes (\wedge^2 U_4) \Rightarrow \wedge^4 U_4 \otimes L,$

p decay : $(U_4 \otimes L) \otimes U_4 \otimes (U_4 \otimes L) \Rightarrow \wedge^3 U_4 \otimes \wedge^2 L.$

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

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.

$$\mathcal{L} = \frac{1}{2g_{\mathrm{YM}}^2} 2\,\mathrm{tr}_f(\mathrm{q}_X^2) D_X^2 + D_X \xi_X + D_X q_{X,i}\psi_i^\dagger\psi_i \to V = \frac{1}{2}\frac{g_{\mathrm{YM}}^2}{2\,\mathrm{tr}_f(\mathrm{q}_X^2)}\left(\xi_X + q_{X,i}\psi_i^\dagger\psi_i\right)^2 .$$

$$\xi_X = \frac{10 M_G^2}{32\pi^2}\left[\frac{2\pi l_s^2}{\mathrm{vol}(Z)}\int c_1(L)\wedge J\wedge J - \frac{g_{\mathrm{YM}}^2 e^{2\tilde{\phi}_4}}{2}\int c_1(L)\left(c_2(V_5) - \frac{1}{2}c_2(TZ)\right)\right].$$

Blumenhagen, Honecker, Weigand '05

Kahler moduli dilaton

The Fayet—Iliopoulos parameter may not vanish.

If $\xi < 0,$

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

$$\xi - 5\left|\bar{N}\right|^2 + 5\left|\bar{\bar{N}}\right|^2 - |10|^2 + 3\left|\bar{5}\right|^2 + 2|H|^2 - 2\left|\bar{H}\right|^2 = 0$$

can be satisfied by $\left\langle \bar{\bar{N}} \right\rangle \neq 0, \quad \left\langle \bar{N} \right\rangle = 0.$

This is equivalent to $0 \to L \to V_5 \to U_4 \to 0.$

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

$\left\langle \bar{\bar{N}} \right\rangle \neq 0.$ R-parity is broken, but....

The underlying $\mathbf{G} = E_8$ gauge symmetry does not allow

$$W \neq \bar{5} \cdot 10 \cdot \bar{5} \cdot \left\langle \bar{\bar{N}} \right\rangle^{n \geq 0} .$$

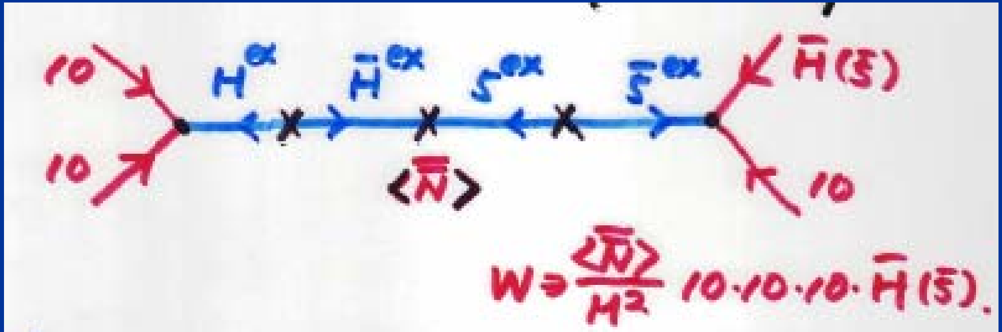
Operators of the form $W = \bar{5} \cdot 10 \cdot \bar{5} \cdot \left\langle \bar{N} \right\rangle$ is allowed,

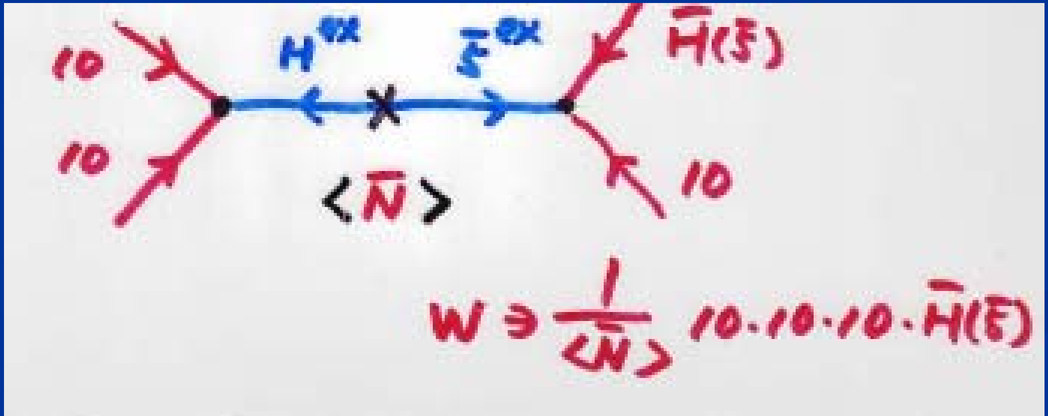
they are not dangerous as long as $\left\langle \bar{N} \right\rangle = 0.$

This can be regarded as the SUSY-zero mechanism
of B-L U(1) gauge symmetry.

LSP Decay

Integrating out heavy states,
R-parity violating oprators 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.