Title: TechniGUT

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Abstract: We propose a grand unified theory (GUT) in which the gauge symmetry is dynamically broken by a strongly coupled gauge interaction, analogous to the chiral symmetry breaking in QCD or technicolor theory. GUT is a beautiful idea and surprisingly consistent with supersymmetry (SUSY). As well as the fact that all the fermions fit to a representation in GUT groups, the three gauge coupling constants meet at a very high energy scale with the particle content of the minimal SUSY standard model. However, the realistic model building of GUT has various difficulties such as the doublet-triplet Higgs mass splitting problem and the too rapid proton decay. Also, since the GUT appears to be a theory at very high energy scale, it is the usual case that there is no definite prediction to the low energy physics. We propose a realistic model without above problems by using the dynamical GUT symmetry breaking. The model provides an interesting predictions to the gaugino mass relation in low energy which should be easily testable with the LHC and a linear collider.

TechniGUT

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hep-ph/0501047

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Introduction

Standard Model

- $SU(3) \times SU(2) \times U(1)$ gauge theory
- quarks + leptons + Higgs boson
- compact and beautiful theory ...

But.

— empirical facts

- neutrino mass $\sim eV$
- baryon asymmetry $n_B/s \sim 10^{-10}$
  $\Omega_B \sim 0.04$
- dark matter $\Omega_{DM} \sim 0.2$
- dark energy $\Omega_\Lambda \sim 0.7$

  ⋮

Almost nothing in the universe is explained by the SM.

— aesthetic issues

- hierarchy problem $M_W \ll M_{Pl}$?
- charge quantization $Q(e^+) = Q(p) = Q(\mu^+)$ ⋮ ?
- strong CP $\theta \lesssim 10^{-10}$?
- fermion mass $m_e \ll m_\mu \ll m_\tau \ll M_W$?

⋮

A Nice picture

Predictions :
light Higgs boson
FCNC , $\not{CP}$
SUSY particles

Supersymmetry
SM + superpartners

Dark matter

non renormalization theorem

Stabilize $M_W \ll M_{Pl}$

gauge coupling unification

Grand Unified Theory

Charge quantization

neutrino mass

leptogenesis
baryon asym.

predictions :
???

Is there any way to see GUT at LHC ?

Grand Unification

Georgi and Glashow (1974)

Standard Model

	SU(3)	SU(2)	U(1)
q	3	2	$1/6$
u^c	$\bar{3}$	1	$-2/3$
d^c	$\bar{3}$	1	$1/3$
l	1	2	$-1/2$
e^c	1	1	1

easiest unification we could think of

$$SU(3) \times SU(2) \to \left(\begin{array}{c|c} SU(3) & \\ \hline & SU(2) \end{array}\right) \quad \underline{SU(5)}$$

$$q : (3,2) \Rightarrow 10^{ab} \ni \underset{q}{(3,2)} + \underset{u^c}{(\bar{3},1)} + \underset{e^c}{(1,1)}$$

rest of them

$$d^c, \, l \Rightarrow \bar{5}_a \ni \underset{d^c}{(\bar{3},1)} + \underset{l}{(2,1)}$$

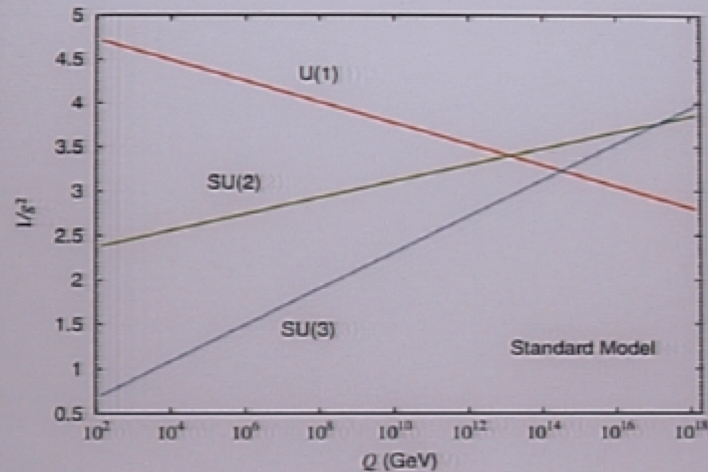
$\Rightarrow 10 + \bar{5}$: anomaly free under SU(5)!

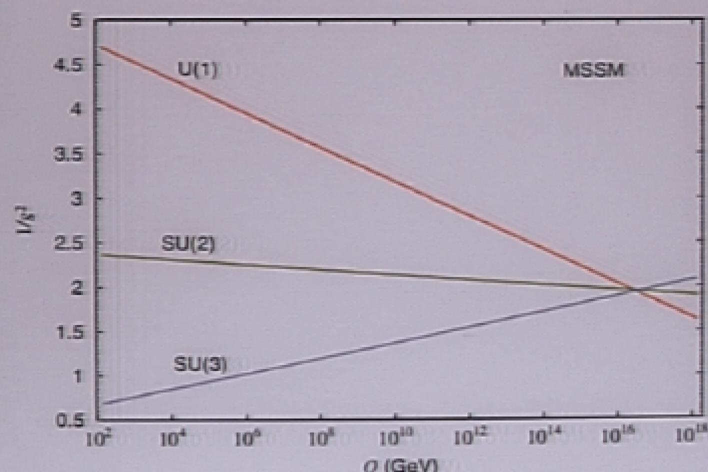
correct hypercharge !

explanation for

$$Q(e^+) = Q(p) = Q(\mu^+) \cdots$$

Gauge coupling unification





⇒ Consistent picture with GUT !

Doublet - Triplet splitting problem

$15 \times \underset{\text{generations}}{\underset{\sim}{3}}$ matters $\longrightarrow (10+\bar{5}) \times 3$

Perfect !

Higgs bosons ? $H : (1,2)_{1/2}$

no 2-dim. rep. in SU(5)

$$\Rightarrow \quad H_5 : \begin{pmatrix} H_c \\ \hline H \end{pmatrix} \begin{matrix} \} \text{ colored Higgs} \\ \} \text{ SM Higgs} \end{matrix}$$

$\Rightarrow$ We need new particles H_c

$\Rightarrow$ H_c screw up the gauge coupling unification if

$$M_{H_c} \ll M_{GUT} \quad \text{or} \quad M_{H_c} \gg M_{GUT}$$

$\Rightarrow$ $M_{H_c} \sim M_{GUT}$

H_c has to be superheavy whereas H is nearly massless.

$\Rightarrow$ GUT symmetry breaking should split those masses.

DT splitting in minimal SU(5) model

GUT breaking : $SU(5) \to SU(3) \times SU(2) \times U(1)$

$$\langle \Sigma_{24} \rangle = \begin{pmatrix} 2v & & & & \\ & 2v & & & \\ & & 2v & & \\ & & & -3v & \\ & & & & -3v \end{pmatrix}$$

$\Uparrow$

$$W_\Sigma = \frac{m}{2} \mathrm{tr}\Sigma^2 + \frac{\lambda}{3} \mathrm{tr}\Sigma^3$$

① $SU(5)$ ② $SU(4) \times U(1)$ ③ $SU(3) \times SU(2) \times U(1)$

$$v = \frac{m}{\lambda}$$

Higgs mass

$$W_{H_c} = m_5 H_5 \bar{H}_{\bar{5}} + k H_5 \Sigma_{24} \bar{H}_{\bar{5}}$$

$$\Rightarrow \begin{cases} M_{H_c} = m_5 + \dfrac{2km}{\lambda} \sim M_{GUT} \\ M_H = m_5 - \dfrac{3km}{\lambda} \lesssim M_W \end{cases}$$

$\Rightarrow$ We need finetuning of $O(10^{-14})$!

Proton decay

Goto, Nihei (1999)
Murayama, Pierce (2002)

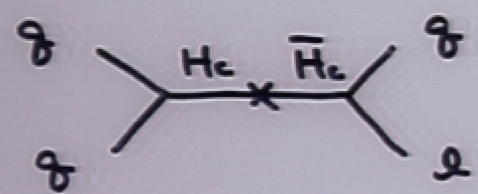
Yukawa coupling

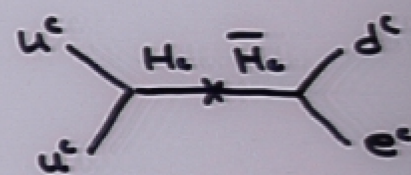
$$W_{\text{YUKAWA}} = f_u\, 10 \cdot 10 \cdot H_5 + f_d\, 10 \cdot \bar{5} \cdot \bar{H}_{\bar{5}}$$

$$10 \supset q,\ u^c,\ e^c$$

$$\bar{5} \supset d^c,\ \ell$$

$\Rightarrow$





$\Delta B = 1$ operators !

$$\frac{f_u f_d}{M_{H_c}}\, qqq\ell \cdots$$

$\Rightarrow$ proton decay

$\Rightarrow$ $M_{H_c} \gtrsim 10^{17}$ GeV

$$\Uparrow$$

$$\tau(p \to K\nu) \geq 6.7 \times 10^{33}\ \text{yrs}$$

while

$$2 \times 10^{14}\ \text{GeV} \lesssim M_{H_c} \lesssim 4 \times 10^{15}\ \text{GeV}$$

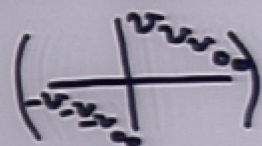
for gauge coupling unification ....

Possible ways to go

GUT symmetry breaking

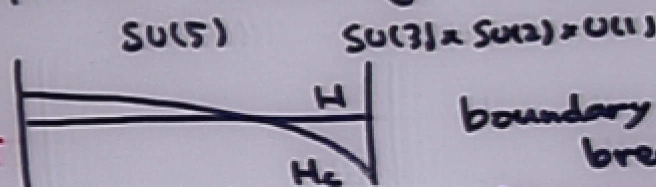
① Higgs mechanism

SO(10) extension $\langle \Sigma_{24} \rangle \to \langle \Sigma_{45} \rangle$



Dimopoulos - Wilczek mechanism

② explicit breaking ⇒ unitarity ?



AdS/CFT

boundary condition breaking

Kawamura (2001)
Altarelli, Feruglio (2001)
Hall, Nomura (2001)

③ dynamical symmetry breaking

$$G \times SU(5) \to SU(3) \times SU(2) \times U(1)$$

strong gauge interaction

subgroup of flavor symmetry

H appears as composite.

We found a pretty model
prediction to LHC.

Possible ways to go

GUT symmetry breaking

① Higgs mechanism

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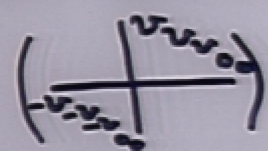

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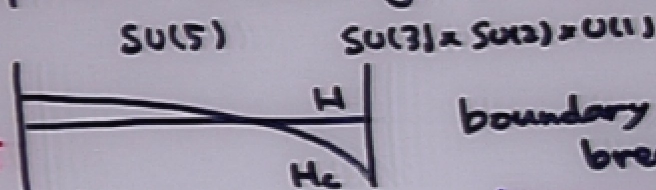

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↑ strong gauge interaction

↑ subgroup of flavor symmetry

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Product group unification

Very closely related approach.

$SU(5) \times SU(2) \times U(1)$ model

Yanagida '94
Ibe, Watari '03

	$SU(5)$	$SU(2) \times U(1)$
H	1	$2_{+1/2}$
$\bar{H}$	1	$2_{-1/2}$
Q	5	$2_{-1/2}$
$\bar{Q}$	$\bar{5}$	$2_{+1/2}$
10	10	1_0
$\bar{5}$	$\bar{5}$	1_0

No colored Higgs

$\times 3$

$$\langle Q \rangle = \langle \bar{Q} \rangle = \begin{pmatrix} 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ v & 0 \\ 0 & v \end{pmatrix}$$

$$SU(5) \times SU(2) \times U(1) \to SU(3) \times SU(2) \times U(1)$$

$$\begin{array}{lcl} SU(5) & \longrightarrow & SU(3) \\ SU(2) & \dashrightarrow & SU(2) \\ U(1) & \dashrightarrow & U(1) \end{array}$$

$H, \bar{H}$ have correct

Model

	$Sp(4)$	$SU(5)$	
T_1	4	1	← $H + \bar{H}$
T_2	4	1	← to avoid Witten anomaly
Q	4	5	
$\bar{Q}$	4	$\bar{5}$	
10	1	10	$\times\ 3$
$\bar{5}$	1	$\bar{5}$	

$$Sp(4) \supset SU(2) \times U(1)$$

$$4 = 2_{+1/2} + 2_{-1/2}$$

$$Sp(4) \times SU(5) \rightarrow SU(3) \times SU(2) \times U(1)$$

$$\langle Q\bar{Q} \rangle \neq 0$$

Very simple.

Symmetry breaking

We can write down superpotentials for $Q, \bar{Q}$'s

$$W = mQ\bar{Q} + \frac{1}{M_1}(\mathrm{tr}\,Q\bar{Q})^2 + \frac{1}{M_2}\mathrm{tr}(Q\bar{Q})^2 + \cdots$$

vacua:

① $SU(5)$ unbroken $\langle Q\bar{Q}\rangle = 0$

$Sp(4)$ 1 flavor (T_1, T_2) — Intriligator Pouliot '95

$\Rightarrow$ run away superpotential

$$W_{eff} \sim \left(\frac{\Lambda^8}{\mathrm{Pf}M}\right)^{1/2}$$

$\Rightarrow$ unstable

② $SU(5) \to SU(4) \times U(1)$ rank$\langle Q\rangle = 1$

$Sp(4)$ 2 flavor

$\Rightarrow$ run away superpotential

$$W_{eff} \sim \frac{\Lambda^7}{\mathrm{Pf}M} \Rightarrow \text{unstable}$$

③ $SU(5) \to SU(3) \times SU(2) \times U(1)$ rank$\langle Q\rangle = 2$

$Sp(4)$ 3 flavor $\Rightarrow$ stable

Model

	$Sp(4)$	$SU(5)$	
T_1	4	1	$\leftarrow H + \bar{H}$
T_2	4	1	$\leftarrow$ to avoid Witten anomaly
Q	4	5	
$\bar{Q}$	4	$\bar{5}$	
10	1	10	$\times 3$
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③ $SU(5) \to SU(3) \times SU(2) \times U(1)$ $\mathrm{rank}\langle Q\rangle = 2$

Sp(4) 3 flavor $\Rightarrow$ stable

Spectrum

$\sqrt{mM}$ $\in X, Y$

m $\in (3,2)_{\pm 1/6}$ $(1,1)_{\pm 1}$

$(1,3)_0$ $(1,1)_0$

massless MSSM $(1,2)_{\pm 1/2}$ $\in T_2$

$W \ni (Q \cdot T_2)(\bar{Q} \cdot T_2)$

if $M \sim M_{pl}$, $m \sim 10^{14}$ GeV

$\Rightarrow$ bad for gauge coupling unification

$$\frac{1}{g_3^2(\mu)} = \frac{1}{g_5^2} + \Delta_3 + \Delta_{MSSM}$$

$$\frac{1}{g_2^2(\mu)} = \frac{1}{g_5^2} + \frac{2}{g_4^2} + \Delta_2 + \Delta_{MSSM}$$

$$\frac{1}{g_1^2(\mu)} = \frac{1}{g_5^2} + \frac{6}{5}\frac{1}{g_4^2} + \Delta_1 + \Delta_{MSSM}$$

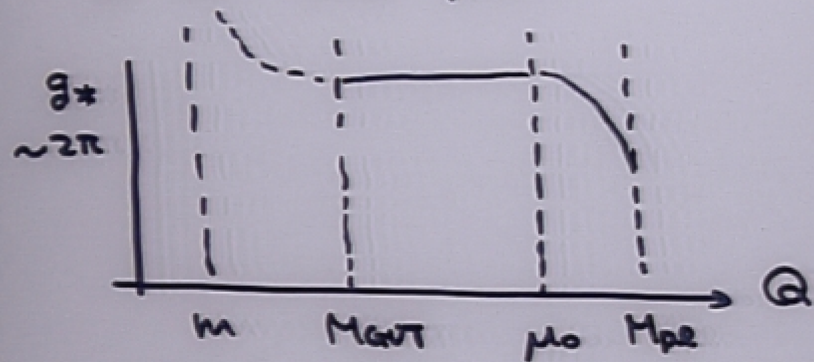
$\Rightarrow$ This requires $m \sim M_{GUT} \sim M \sim \Lambda \sim 10^{16}$ GeV

$\Rightarrow$ Actually, this is not a coincidence problem.

CFT

Our model : Sp(4) 6 flavor gauge theory

$\Rightarrow$ IR fixed point!



$g_4(M_{GUT}) \gg g_5$ is justified

g_4 is always large

- large anomalous dimension

$$D(Q\bar{Q}) = \frac{3}{2}$$

$$\Rightarrow \; mQ\bar{Q} : \quad m(\mu) = m(\mu_0)\left(\frac{\mu}{\mu_0}\right)^{-1/2}$$

$$\frac{1}{M}(Q\bar{Q})^2 : \quad \frac{1}{M(\mu)} = \frac{1}{M(\mu_0)}\left(\frac{\mu}{\mu_0}\right)^{-1}$$

$\Rightarrow$ Enhance in low energy!

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Sp(4) 2 flavor

CFT

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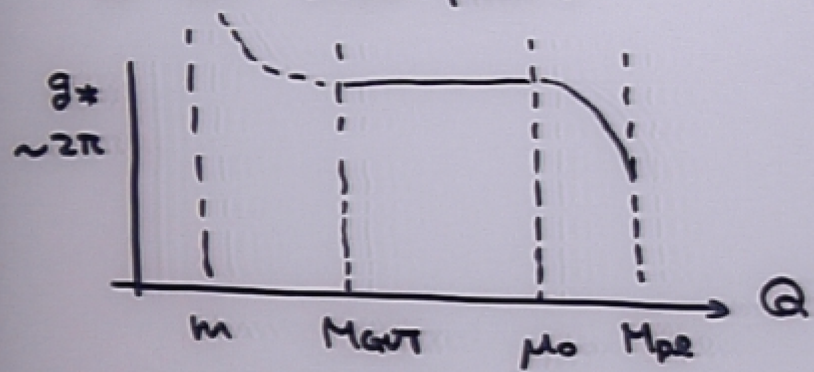

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$\frac{1}{M}(Q\bar{Q})^2$: $\frac{1}{M(\mu)} = \frac{1}{M(\mu_0)} \left(\frac{\mu}{\mu_0} \right)^{-1}$

$\Rightarrow$ **Enhance in low energy !**

for $\frac{1}{M(M_{pl})} \sim \frac{1}{M_{pl}}$ and if the theory is CFT already at M_{pl},

$$\frac{1}{M(M_{GUT})} = \frac{1}{M_{pl}}\left(\frac{M_{GUT}}{M_{pl}}\right)^{-1} = \frac{1}{M_{GUT}} \; !$$

$\Rightarrow \; M \sim M_{GUT}$

M runs linearly w.r.t. energy scale

$m(M_{GUT}) = M_{GUT}$ ⇐ origin of the GUT scale

$$m(M_{pl}) = M_{GUT}\left(\frac{M_{GUT}}{M_{pl}}\right)^{\frac{1}{2}} \sim 10^{15}\,\text{GeV}$$

a little bit lower scale

$\Rightarrow$ Natural explanation for the right-handed neutrino mass

$$m_\nu \simeq \frac{\langle H\rangle^2}{M_R} \simeq 0.1\,\text{eV}$$

$\Rightarrow \; M_R \sim 10^{14}$ GeV

Yukawa coupling

CFT also enhances the Yukawa couplings in low energy

$$W_{\text{YUKAWA}} = \frac{1}{M_U} 10 \cdot 10 \cdot (QT_1)$$

$$+ \frac{1}{M_D} 10 \cdot \bar{5} \cdot (\bar{Q}T_1)$$

$$\frac{1}{M_U(M_{GUT})} = \frac{1}{M_U(M_{pl})} \cdot \left(\frac{M_{GUT}}{M_{pl}} \right)^{-\frac{1}{2}}$$

we need $\frac{1}{M_U(M_{GUT})} \sim \frac{0.5}{M_{GUT}}$

for top-quark

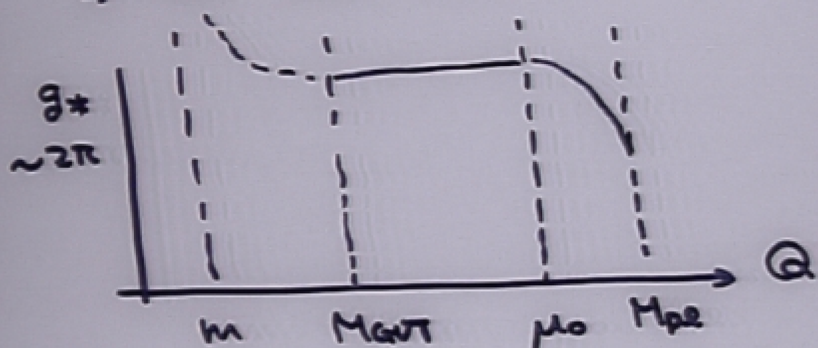
$$\Rightarrow \frac{1}{M_U(M_{pl})} \sim \frac{5}{M_{pl}}$$

good.

CFT

Our model : $Sp(4)$ 6 flavor gauge theory

$\Rightarrow$ IR fixed point !



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Very simple.

Prediction to LHC

gaugino mass relation

$SU(2)_L \times U(1)_Y \in$ mixture of $SU(5) \times Sp(4)$

$$\Rightarrow \quad \frac{M_3}{\alpha_3} = \frac{M_5}{\alpha_5}$$

$$\frac{M_2}{\alpha_2} = \frac{M_5}{\alpha_5} + \frac{2M_4}{\alpha_4}$$

$$\frac{M_1}{\alpha_1} = \frac{M_5}{\alpha_5} + \frac{6}{5}\frac{M_4}{\alpha_4}$$

$$\Rightarrow \quad \frac{M_1}{\alpha_1} - \frac{3}{5}\frac{M_2}{\alpha_2} - \frac{2}{5}\frac{M_3}{\alpha_3} = 0$$

Modified gaugino mass relation

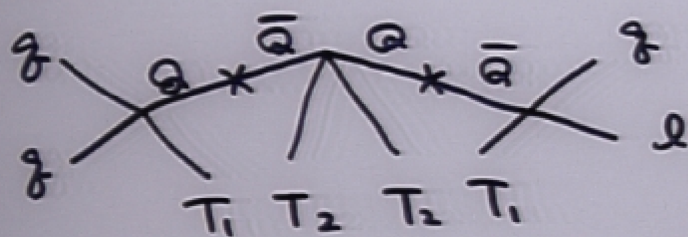
(one-loop RGE invariant)

Arkani-Hamed, Cheng
Moroi '96
Kurosawa, Nomura
Suzuki '99

Proton decay

no dim. 5 operator at the classical level

but ..



$$\Rightarrow \frac{f_u f_d}{M_T m^2 v^2} \; q \cdot q \cdot q \cdot l \; (T_1 \cdot T_2)(T_1 \cdot T_2)$$

$$\langle T_1 \cdot T_2 \rangle \sim \frac{\Lambda^6}{v^4}$$

$$\Rightarrow W_{eff} \sim \frac{f_u f_d \Lambda^{12}_{(2)}}{M_T m^2 v^{10}} \; q \cdot q \cdot q \cdot l$$

$$\Rightarrow M^{eff}_{Hc} \sim \frac{M_T m^2 v^{10}}{\Lambda^{12}} \sim v \cdot \left(\frac{v}{m}\right)^{11} \gtrsim 10^{17} \text{GeV}$$

$\Rightarrow$ easily satisfied

Prediction to LHC

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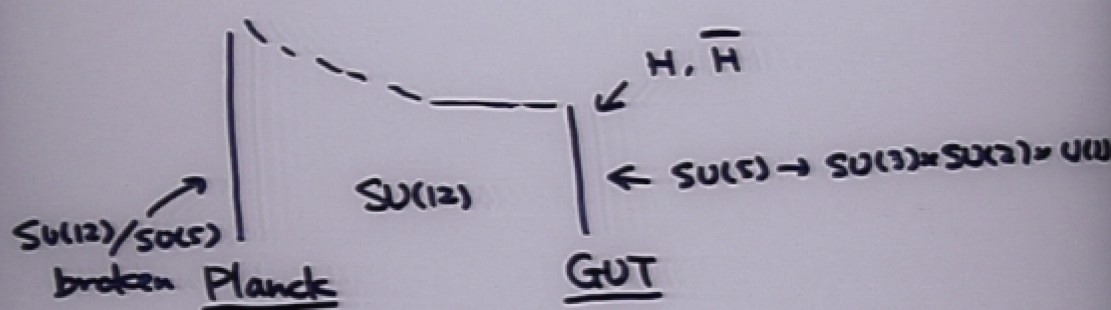
AdS ?

There might be AdS interpretation.



Similar to Hebecker and March-Russel model.

CFT side says

- Uniqueness of the rank = 2 vacuum.
- special gaugino mass relation.

Summary

- We can successfully remove colored Higgs.
- CFT helps
  1. naturally large coupling
  2. enhancement of higher dim. operators.
- gaugino mass relation may show the evidence of the model.

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Modified gaugino mass relation

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$$\frac{1}{M}\overset{1}{Q}\overset{1}{Q}\overset{1}{Q}\overset{1}{L}$$

$$\overset{1}{Q}\overset{-2}{H}\overset{1}{U^c}$$

$$\overset{-2}{H_u}\quad\overset{-2}{\bar{H}}$$