Orbifold SUSY GUT from the Heterotic String

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(KIAS)

based on

0712.1596 [hep-th]

hep-ph/0702278

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Gauge Coupling Unification in the MSSM

$$\Big\{ g_3 ,\ g_2 ,\ \overset{\text{“}g_1\text{”}}{\sqrt{\tfrac{5}{3}}\, g_Y} \Big\} \quad \text{unified at} \quad 10^{16}\,\text{GeV}$$

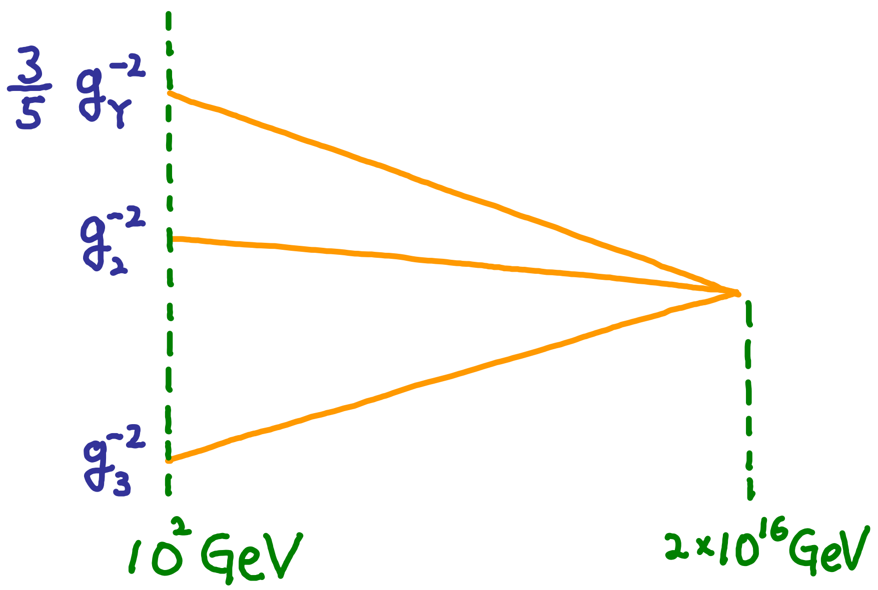
GUT normalization

SU(5), SO(10), ⋯

$$\begin{cases} Y[Q] = \frac{1}{6} \\ Y[u^c] = \frac{-2}{3} \\ Y[d^c] = \frac{1}{3} \\ \quad \vdots \\ \quad \text{etc} \end{cases}$$

$$\sqrt{\tfrac{3}{5}}\, Q_Y \equiv Q_1$$

$$\longrightarrow \quad \sin^2\theta_W^0 = \frac{g_Y^2}{g_2^2 + g_Y^2} = \frac{3}{8}$$



Problems in GUT

D/T splitting problem

Difficult to avoid the relation

$$m_d = m_e$$

Even spontaneous breaking for G_{SM} w/o remaining unwanted (pseudo-) Goldstones & fine tuning in GUTs is non-trivial.

i.e.

Even gauge coupling unification consistent with $\sin^2\theta_W\big|_{M_Z} \approx 0.23$ in GUTs is non-trivial.

5D SUSY GUT

Kawamura (2000), Hall & Nomura (2001)

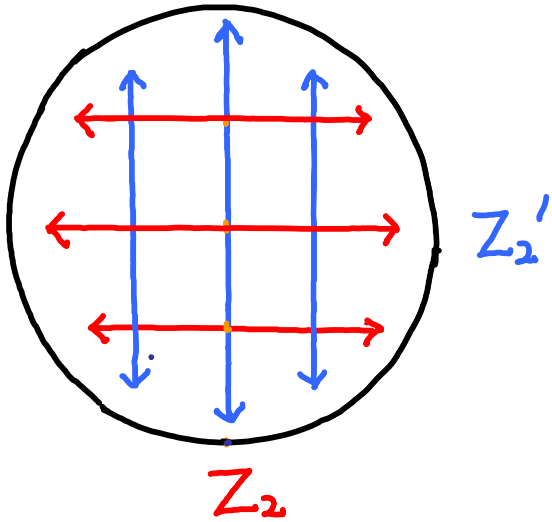
e.g.

$S^1/Z_2 \times Z_2'$

$\downarrow$

$Z_2 \times$ transl.

$g: (\theta, v)$



$$\underset{\text{SU(5)}}{\overset{\text{5D}}{N=2 \text{ SUSY}}} \quad \underset{\mu \gtrsim \frac{1}{R} \qquad \mu \lesssim \frac{1}{R}}{\xleftrightarrow{\text{KK}}} \quad \underset{\text{SM}}{\overset{\text{4D}}{N=1 \text{ SUSY}}}$$

Gauge

$$A_\mu^{SM\,++} \qquad \lambda_1^{SM\,++} \qquad \lambda_2^{SM\,--} \qquad A_y^{SM}, \phi^{SM\,--}$$

N=2 SUSY

$$A_\mu^{SU(5)/SM\,+-} \qquad \lambda_1^{SU(5)/SM\,+-} \qquad \lambda_2^{SU(5)/SM\,-+} \qquad A_y^{SU(5)/SM}, \phi^{SU(5)/SM\,-+}$$

N=2 SUSY

Hyper

$$5 = \begin{bmatrix} 3^{+-} \\ \hline H_u^{++} \end{bmatrix}, \qquad \bar{5} = \begin{bmatrix} \bar{3}^{+-} \\ \hline H_d^{++} \end{bmatrix}$$

$$\updownarrow \text{N=2} \qquad\qquad \updownarrow \text{N=2}$$

$$5^c = \begin{bmatrix} 3^{c\,-+} \\ \hline H_u^{c\,--} \end{bmatrix}, \qquad \bar{5}^c = \begin{bmatrix} \bar{3}^{c\,-+} \\ \hline H_d^{c\,--} \end{bmatrix}$$

D/T splitting !!

Need to be realized
in a fundamental theory
such as the string theory.

Heterotic String Theory

- unification framework [for gauge coupling unif.]
- Structure is rich enough to accommodate the MSSM

[Dixon, Harvey, Vafa, Witten '85, '86]

Orbifold Compactification

to reduce space dim, SUSY, gauge sym.

- relatively simple, easy to analyze
- CFT is still useful [Yukawa coupl.]

String Compactification on Prime Orbifolds ?

		# of T or U moduli
Prime : Z_3, Z_7	:	0
Z_{6-I}, Z_{8-I}, Z_{12-I}	:	1
Z_4 Z_{8-II}, Z_{12-II}	:	2
Z_{6-II}	:	3

simplest for studying KK

[Dixon, Kaplunovsky, & Louis '91]

Non-Prime Orbifold

For instance in $\mathbb{Z}_{12\text{-}I}$ 　　SO(8) × SU(3) lattice

$$\phi = \left(\tfrac{5}{12}\ \tfrac{4}{12}\ \tfrac{1}{12} \right) .$$

SU(3)

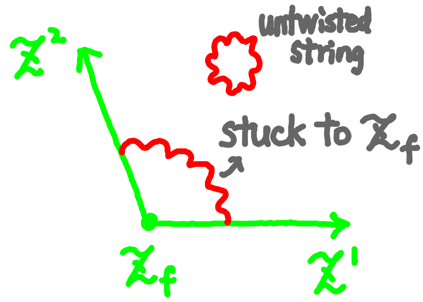
$$Z^a_{L,R}(\sigma+2\pi) = e^{2\pi i \phi_a} Z^a_{L,R}(\sigma)$$

$$\psi^a_R(\sigma+2\pi) = \quad '' \quad \psi^a_R(\sigma)$$

$$X^I_L(\sigma+2\pi) = X^I_L(\sigma) + 2\pi V^I$$

$a = \{1, 2, 3, \bar{1}, \bar{2}, \bar{3}\}$

$I = \{10, 11, \cdots, 25\}$



Modular Inv. requires to consider all the sectors with the boundary conditions,

$$0 \times \phi ,\quad 1 \times \phi ,\quad 2 \times \phi ,\quad \cdots ,\quad 11 \times \phi .$$

$$U \qquad T_1 \qquad T_2 \qquad \qquad T_{11}$$

In T_3, where

$3 \times \phi = \left(\frac{5}{4} \quad 1 \quad \frac{1}{4}\right)$ imposed,

$\big\downarrow \sim 0$

untwisted B.C.

2nd 2D sub-lattice is invariant under orbifold action.

Just an ordinary Torus!

(No fixed Points)

→ untwisted string

The informations of Background Moduli

such as Radius (or metric)

can be encoded only in the

zero mode's momenta of untwisted bosonic strings.

〃 3, 4

$$X^{i}(\sigma \tau) = x^{i} + 2\sigma n^{i} + \tau\left(g^{ik} m_{k} - 2B^{i}_{k} n^{k}\right)$$

[Narain, Sarmadi, Witten '87]

$\Rightarrow$ **KK excitations**

$\underline{3 \times \phi}$ preserves $\underline{N=2}$ SUSY.

$\shortparallel$

$(\frac{5}{4}\ 1\ \frac{1}{4})$

$$Q_{(10)} = Q_{(4)} \otimes Q_{(6)}$$

$$Q_{(6)} \longrightarrow e^{2\pi i \overbrace{S\cdot 3\phi}} Q_{(6)}$$

SO(8) weight

$S \cdot \boxed{3}\phi$ = integer only for

$$S = \begin{cases} (\oplus; +--) \\ (\oplus; --+) \\ (\ominus; -++) \\ (\ominus; ++-) \end{cases}$$

c.f. e.g. in T_1 only $N=1$ SUSY preserved with $S \cdot \boxed{1}\phi$ = integer

In $Z_{12\text{-}I}$, among $\{U, T_1, T_2, \cdots, T_{11}\}$,

only $\{U, T_3, T_6, T_9\}$ sectors

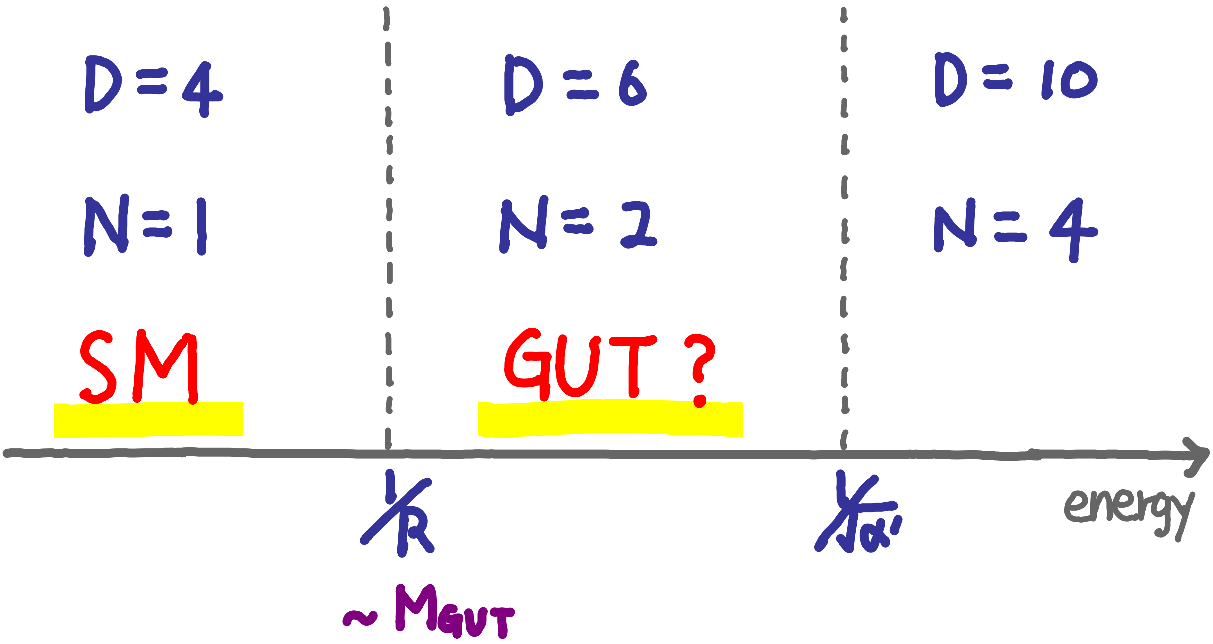
provide KK states with enhanced SUSY.

The other sectors provide only

(massless) $N=1$ chiral multiplets.

So if $R \gtrsim \sqrt{\alpha'}$,

$\sim 1/M_{GUT}$



Indeed, in orbifold compactification, ($N=4$ or $N=2$) SUSY breaking should be accompanied with Gauge sym. breaking by modular invariance.

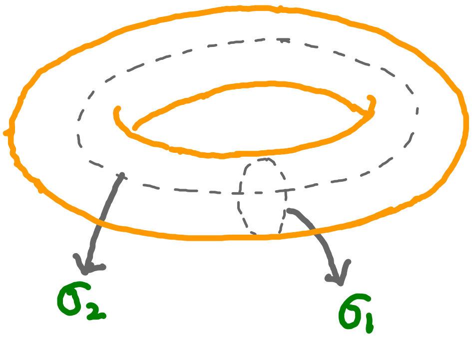
To see the 6D theory,

What are the relevant Mass-shell condition and GSO projetor governing KK spectra?

Need to analyze the partition function.

Partition Function

boundary condi.s



$$\theta \equiv e^{2\pi i \phi}$$

$$\begin{cases} X^i_{L,R}(\sigma_1 = 2\pi) = (\theta^{k} X_{L,R})^i(\sigma_1 = 0) + z^a e^i_a \\ X^i_{L,R}(\sigma_2 = 2\pi) = (\theta^{l} X_{L,R})^i(\sigma_2 = 0) + z'^a e^i_a \end{cases}$$

$$\begin{cases} X^I_L(\sigma_1 = 2\pi) = X^I_L(\sigma_1 = 0) + k V^I + \xi^a W^I_a \\ X^I_L(\sigma_2 = 2\pi) = X^I_L(\sigma_2 = 0) + l V^I + \xi'^a W^I_a \end{cases}$$

$$\begin{cases} \psi^i_R(\sigma_1 = 2\pi) = \pm(\theta^{k} \psi_R)^i(\sigma_1 = 0) \\ \psi^i_R(\sigma_2 = 2\pi) = \pm(\theta^{l} \psi_R)^i(\sigma_2 = 0) \end{cases}$$

$$\text{Partition Function} \equiv \sum_{k,l} \begin{bmatrix} k \\ l \end{bmatrix}$$

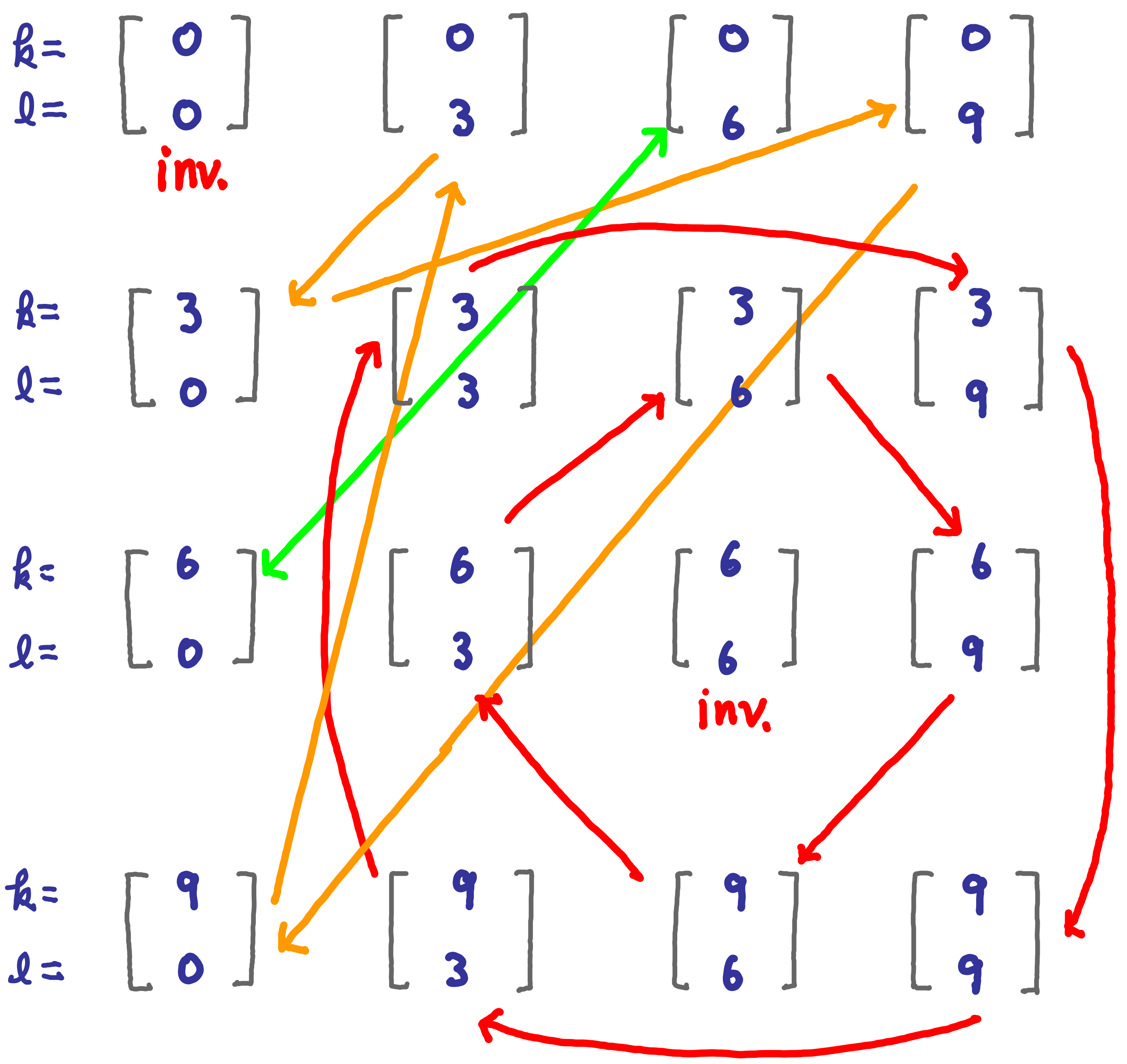
in the σ_1 direction, $k \times \phi$, $k \times V^I$ imposed on $X^i_{L,R}$, X^I_L, ψ^i_R

in the σ_2 direction, $l \times \phi$, $l \times V^I$ imposed

$$\tau \to -1/\tau \quad S: \begin{bmatrix} k \\ l \end{bmatrix} \longrightarrow \begin{bmatrix} l \\ -k \end{bmatrix}$$

$$\tau \to \tau + 1 \quad T: \begin{bmatrix} k \\ l \end{bmatrix} \longrightarrow \begin{bmatrix} k \\ l + k \end{bmatrix}$$

S - transformation



The sectors w/ k and l = 0,3,6,9 decoupled from others.

T - transformation

$$\begin{array}{l} k= \\ l= \end{array} \begin{bmatrix} 0 \\ 0 \end{bmatrix} \quad \begin{bmatrix} 0 \\ 3 \end{bmatrix} \quad \begin{bmatrix} 0 \\ 6 \end{bmatrix} \quad \begin{bmatrix} 0 \\ 9 \end{bmatrix}$$

inv. inv. inv. inv.

$$\begin{array}{l} k= \\ l= \end{array} \begin{bmatrix} 3 \\ 0 \end{bmatrix} \rightarrow \begin{bmatrix} 3 \\ 3 \end{bmatrix} \rightarrow \begin{bmatrix} 3 \\ 6 \end{bmatrix} \rightarrow \begin{bmatrix} 3 \\ 9 \end{bmatrix}$$

$$\begin{array}{l} k= \\ l= \end{array} \begin{bmatrix} 6 \\ 0 \end{bmatrix} \quad \begin{bmatrix} 6 \\ 3 \end{bmatrix} \quad \begin{bmatrix} 6 \\ 6 \end{bmatrix} \quad \begin{bmatrix} 6 \\ 9 \end{bmatrix}$$

$$\begin{array}{l} k= \\ l= \end{array} \begin{bmatrix} 9 \\ 0 \end{bmatrix} \leftarrow \begin{bmatrix} 9 \\ 3 \end{bmatrix} \leftarrow \begin{bmatrix} 9 \\ 6 \end{bmatrix} \leftarrow \begin{bmatrix} 9 \\ 9 \end{bmatrix}$$

The sectors w/ k and $l = 0,3,6,9$ decoupled from others.

KK states arise only from the sectors with k and $\ell = 0, 3, 6, 9$.

X^3, X^4 $\quad$ X^1, X^2, X^5, X^6

$$\text{Partition Function} = \frac{1}{\lambda^2}\left[\sum_{\vec{\mu},\vec{\xi}} \frac{q^{(\vec{L}+\vec{\xi})^2/2}}{[\eta(\tau)]^2}\,\frac{\bar{q}^{(\vec{L}-\vec{\xi})^2/2}}{[\bar{\eta}(\bar{\tau})]^2}\right] \times \left|\hat{Z}^{X}_{[k\ell]}\right|^2$$

$$\times\left[\sum_{P,s} \frac{q^{(L^I)^2/2}}{[\eta(\tau)]^{16}}\,\frac{\bar{q}^{(\tilde{L})^2/2}}{[\bar{\eta}(\bar{\tau})]^4} \times e^{2\pi i \ell \Theta_k}\right]$$

Dedekind η-function

[Kim, Kyae '07]

$$q = e^{2\pi i \tau}$$

$$\vec{L} = \sum_{a,b=3,4}\left[\frac{m_a}{2\lambda R}\sqrt{\alpha'} - \left(P^I + \frac{kV^I}{2} + \frac{\xi^b W_b}{2}\right)\frac{W_a^I}{2}\right]\vec{e}^{*a}$$

$$L^I = P^I + kV^I + \xi^a W_a^I\,, \quad \tilde{L} = s + k\phi$$

$$\ell\times\Theta_k = \ell\times\left[\left(P^I + \frac{k}{2}V^I + \frac{\xi^a}{2}W_a^I\right)V^I - \left(s + \frac{k}{2}\phi\right)\phi\right] + \frac{6}{\lambda}m_a\xi^a$$

	$k=0$	$k=3$	$k=6, \ell=0,6$	$k=6, \ell=\pm 3$	$k=9$
λ	1	4	2	-2	-4
σ	0	$\ell/3$	$\ell/6$	$-1/2$	$4-\ell/4$

KK massive modes (for non-critical $R \gtrsim \sqrt{\alpha'}$)

$$M_{KK}^2 \overset{\vec{\xi}=0}{=} \sum_{\substack{m_a, m_b \\ = \text{integers}}} \frac{g^{ab}}{2R^2} [\underset{\text{integer}}{m_a} - \underbrace{P \cdot W_a}_{}][\underset{\text{integer}}{m_b} - P \cdot W_b]$$

integer, $E_8 \times E_8'$ weight, Wilson line

mass-shifting by Wilson line !

$g^{ab} = \frac{1}{3}\begin{pmatrix} 2 & 1 \\ 1 & 2 \end{pmatrix}$

In the GSO projector, $P_k = \frac{1}{N} \sum_{\ell} \tilde{\chi}(k,\ell) e^{2\pi i \ell \Theta_k}$

k and ℓ = 0, 3, 6, 9 , $N = 4$

$k \backslash \ell$	0	3	6	9
0	1	1	1	1
3	4	4	4	4
6	16	4	16	4
9	4	4	4	4

$\therefore$ e.g. in U and T_3 sectors,

$$\Theta_k \equiv (P + \tfrac{k}{2} V) V - (s + \tfrac{k}{2} \phi)\phi \pm \sum_i (N_i^L - N_i^R)\phi_i$$

$$\underset{\text{Should}}{=} \frac{1}{3} \times \text{integer}$$

↳ 1 for massless modes in U

For instance, in the U sector ($k=0$) of $Z_{12\text{-}I}$,

	KK massive	Massless
Gauge	$3 \times P\cdot V = \text{integer}$ $\left(3 \times P\cdot V = 3\times s\cdot\phi = \text{integer}\right)$	$1 \times P\cdot V = \text{integer}$ $P\cdot W = \text{integer}$

more relaxed ⟷ more constrained

Matter

$$P\cdot V = \begin{cases} \frac{-5}{12} \bmod \frac{1}{3} = \frac{-5}{12}, \frac{-1}{12}, \frac{+3}{12}, \cdots \\ \frac{1}{12} \bmod \frac{1}{3} = \frac{+5}{12}, \frac{+1}{12}, \frac{-3}{12}, \cdots \end{cases}$$

$$\begin{cases} P\cdot V = \left\{\frac{-5}{12}\ \frac{1}{12}\ \frac{4}{12}\right\} \bmod \text{integer} \\ P\cdot W = \text{integer} \end{cases}$$

$\Downarrow$ vec.-like | $\Downarrow$ chiral

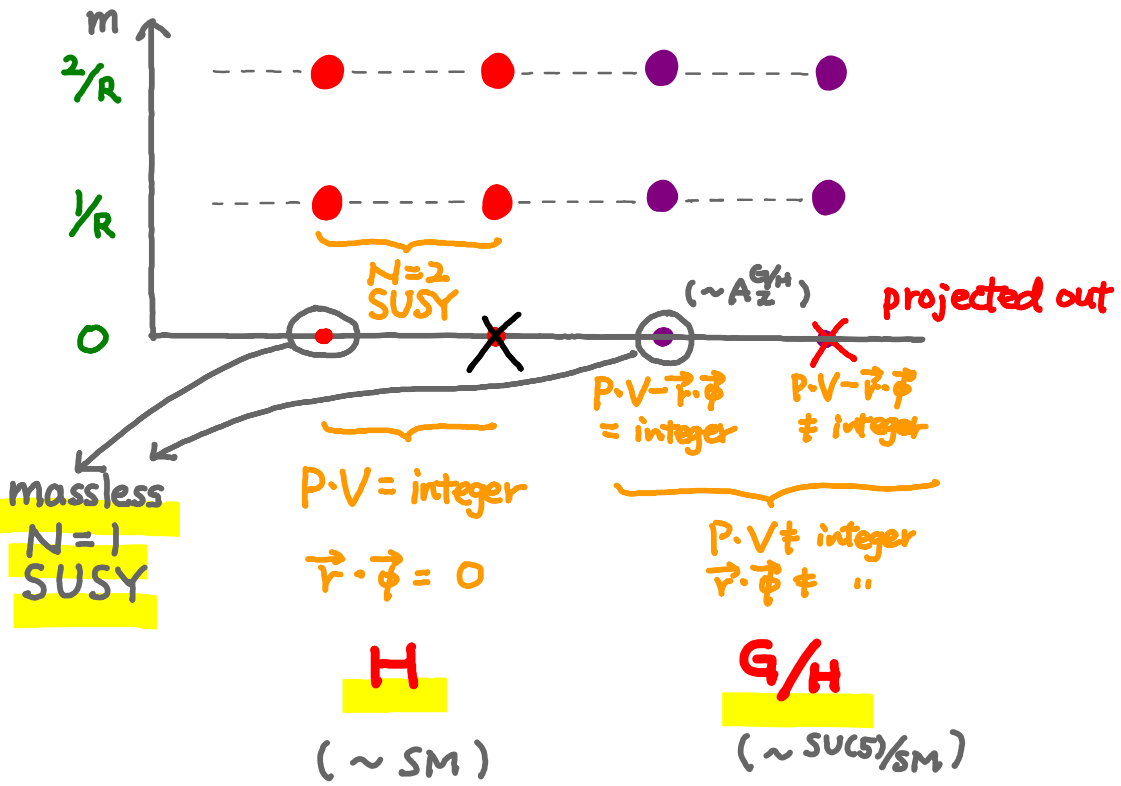
N=2 SUSY ⟷ N=1 SUSY

$G \longleftrightarrow H$ gauge sym. broken

$\mu \gtrsim \frac{1}{R}$ $\qquad$ $\mu \lesssim \frac{1}{R}$

$N=2$ SUSY $\longleftrightarrow$ $N=1$ SUSY

If there is no Wilson Line,



NOTE if $\exists$ Wilson Line,

KK towers with $P \cdot W \neq$ integer are lifted up.

$\Rightarrow$ Gauge Sym. is further broken.

Threshold Correction

$$\frac{4\pi}{\alpha(\mu)} = \frac{4\pi}{\alpha_*} + b^0 \log\frac{M_*^2}{\mu^2} + \Delta \quad \text{for level 1}$$

$$\Delta = \frac{|G'|}{|G|} \cdot b^{N=2} \int_{\Gamma} \frac{d^2\tau}{\tau_2^2}\left(\hat{Z}_{torus} - 1\right), \text{ where}$$

$$\hat{Z}_{torus} \equiv \sum_{\vec{P}_L, \vec{P}_R} q^{P_L^2/2}\, \bar{q}^{P_R^2} = \sum_{\vec{\mu}, \vec{\xi}} q^{(\vec{\mu}+\vec{\xi})^2/2}\, \bar{q}^{(\vec{\mu}-\vec{\xi})^2/2}$$

Kaplunovsky '88
Dixon, Kaplunovsky, Louis '91
Antoniadis '90

$$\frac{4\pi}{g_H^2(\mu)} \approx \frac{4\pi}{g_*^2} + b_H^{\overset{N=1}{0}} \ln\frac{M_*^2}{\mu^2} - \frac{1}{4} b_G^{N=2} \ln\frac{M_*^2}{M_R^2}$$

w/o Wilson line

$\Downarrow$ (Not $b_H^{N=2}$)

$$+ \frac{1}{4} b_G^{N=2}\left[\frac{2\pi}{\sqrt{3}}\frac{M_*^2}{M_R^2} - 2.19\right]$$

reliable

However,

Wilson line shifts up (KK) masses,
and Gauge Sym. is further broken.

PW = integer

N=1

$$\frac{4\pi}{g^2_{H_0}(\mu)} \approx \frac{4\pi}{g^2_*} + b^{0}_{H_0} \ln\frac{M^2_*}{\mu^2} - \frac{b^{N=2}_{H}}{4}\left[\ln\frac{M^2_*}{M^2_R} + 1.89\right]$$

W/ Wilson line

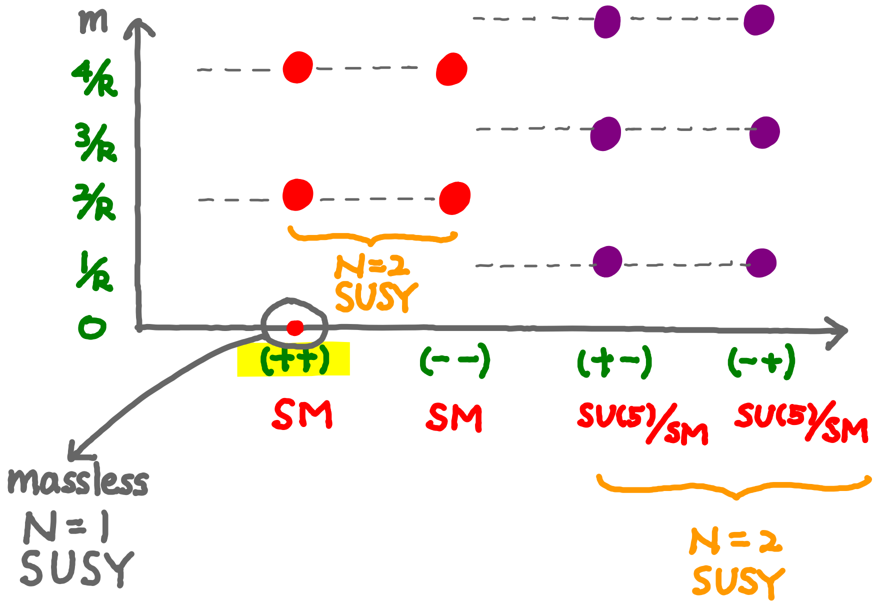
$$+ \frac{1}{4} b^{N=2}_{G}\left[\frac{2\pi}{\sqrt{3}}\frac{M^2_*}{M^2_R} - 0.30\right]$$

[Kim, Kyae '07]

Unification scale can be higher than 10^{16} GeV.

KK Tower in orbiford Field Th.

[Hall, Nomura '01]



KK mass Lifting

even W/o

Wilson Line

SM

$$\frac{2\pi}{g_i^2(\mu)} \approx \frac{2\pi}{g_*^2} + \overbrace{b_i^0}^{N=1} \ln\frac{\Lambda}{\mu} - \overbrace{(b_i^{++} + b_i^{--})}^{N=2\ \equiv\ b_{SM}^{N=2}} \ln\frac{\Lambda}{M_R}$$

(Not $b_G^{N=2}$)

$$+ \underbrace{\Big(\underbrace{b_i^{++} + b_i^{--}}_{SM} + \underbrace{b_i^{+-} + b_i^{-+}}_{SU(5)/SM} \Big)}_{N=2,\ SU(5)\ \equiv\ b_{SU(5)}^{N=2}} \left[\frac{\Lambda}{M_c} - 1 \right]$$

linearly div.

not reliable

In higher dim. Field Theory,

Orbifolding acts on Fields (space-time fn.)

$\longrightarrow$ associated with curvatures $(\sim -\partial_y^2)$

or masses

Sym. breakings are decoupling process.

In string theory,

Orbifold Sym. breaking is

associated with GSO projection.

The Model

[Kim, Kim, Kyae hep-ph/0702278]

Z_{12-I} orbifold compactification

$$\vec{\phi} = \left(\frac{5}{12}, \frac{4}{12}, \frac{1}{12}\right)$$

: SO(8)×SU(3) lattice

$\sim Z_3$ { Wilson line of order 3 can be set on this sub-lattice

leads to $N=1$ SUSY in 4d

Shift vector:

$$V = \left(\frac{1}{4}\ \frac{1}{4}\ \frac{1}{4}; \frac{1}{4}\ \frac{1}{4}; \frac{5}{12}\ \frac{5}{12}\ \frac{1}{12}\right)\left(\frac{1}{4}\ \frac{3}{4}\ 0; 0^5\right)'$$

SU(3) SU(2) SO(10)'

Wilson line

$$W = \left(\frac{2}{3}\ \frac{2}{3}\ \frac{2}{3}; \frac{-2}{3}\ \frac{-2}{3}; \frac{2}{3}\ 0\ \frac{2}{3}\right)\left(0\ \frac{2}{3}\ \frac{-2}{3}; 0^5\right)'$$

Untwisted Sector

⊙ Gauge Sector :

$P\cdot V - \vec{r}\cdot\vec{\phi} = 0 \mod Z$
$P\cdot V = \vec{r}\cdot\vec{\phi} = 0 \mod Z$

The root vectors P of $E_8 \times E_8'$ satisfying

$$P\cdot V = P\cdot W = \text{integer}$$

$(\underline{1\ {-1}\ 0};\ 0\ 0;\ 0^3)(0^8)'$: $SU(3)$

$(0\ 0\ 0;\ \underline{1\ {-1}};\ 0^3)(0^8)'$: $SU(2)$

$(0^8)'(0^3;\ \underline{\pm1\ \pm1\ 0\ 0\ 0})'$: $SO(10)'$

$$\boxed{G = SU(3)_c \times SU(2)_L \times U(1)_Y \times U(1)^4 \times [\,SO(10) \times U(1)^3\,]'}$$

Hypercharges are defined with

$$Y = \left(\frac{1}{3}\,\frac{1}{3}\,\frac{1}{3};\,\frac{-1}{2}\,\frac{-1}{2};\,0^3\right)'\left(0^8\right)'$$

GUT

The current algebra in the heterotic string theory fixes the normalization of Y:

$$Z_{\text{string}} \equiv u \times Y = u \times \left[\sqrt{\frac{2}{3}}\,\frac{\vec{g}_3}{\sqrt{2}} - \frac{\vec{g}_2}{\sqrt{2}}\right]$$

$$\left.\begin{aligned}\vec{g}_3 &= \frac{1}{\sqrt{3}}(1\,1\,1;\,0\,0;\,0^3)(0^8)' \\ \vec{g}_2 &= \frac{1}{\sqrt{2}}(0\,0\,0;\,1\,1;\,0^3)(0^8)'\end{aligned}\right\}\ \text{orthonormal bases}$$

$$u^2\left(\frac{2}{3}+1\right) = 1 \quad \text{or} \quad u^2 = \frac{3}{5}$$

$$\therefore\ g_1^2 = \frac{5}{3}\,g_Y^2 \longrightarrow \sin^2\theta_W = \frac{3}{8}$$

SU(5) or SO(10)-like

Untwisted Sector

⊙ Matter Sector :

$P \cdot V - \vec{r} \cdot \vec{\phi} = 0 \mod \mathbb{Z}$

$P \cdot V = \vec{r} \cdot \vec{\phi} \mod \mathbb{Z}$

The root vectors P of $E_8 \times E_8'$ satisfying

$$P \cdot V = \underbrace{\left\{ \tfrac{-5}{12}, \tfrac{4}{12}, \tfrac{1}{12} \right\}}_{\mathrm{mod}\ \mathbb{Z}}, \quad P \cdot W = \text{integer}$$

$\pm \equiv \pm\frac{1}{2}$

$\frac{-5}{12}$:

$(\underline{++-};\underline{+-};+++)(0^8)'$: Q

$(---;\underline{+-};+--)(0^8)'$: L

$\frac{1}{12}$:

$(\underline{+--};--;+++)(0^8)'$: d^c

$(+++;++;+++)(0^8)'$: ν^c

$(\underline{+--};++;+--)(0^8)'$: u^c

$(+++;--;-+-)(0^8)'$: e^c

16
Spinor

$\frac{4}{12}$:

$(0\,0\,0;\underline{1\,0};0\,0\,1)(0^8)'$: H_d

$(0\,0\,0;\underline{-1\,0};-1\,0\,0)(0^8)'$: H_u

$(0\,0\,0;0\,0;1\,0\,-1)(0^8)'$: 1_0

D/T splitting
vec. type

T_4° Sector

$$\begin{cases} 4\times\vec{\phi} = \left(\frac{5}{3}\ \frac{4}{3}\ \frac{1}{3}\right) \\ 4\times V^I \end{cases}$$

Massless modes of $P+4V$

$$2\times\left\{\begin{array}{lcl}
(\underline{+--};--;\ \frac{1}{6}\frac{1}{6}\frac{-1}{6})(0^8)' & : & d^c \\
(---;\underline{+-};\ \frac{1}{6}\frac{1}{6}\frac{-1}{6})(\,''\,)' & : & L \\
(\underline{+--};++;\ \frac{1}{6}\frac{1}{6}\frac{-1}{6})(\,''\,)' & : & u^c \\
(\underline{++-};\underline{+-};\ \frac{1}{6}\frac{1}{6}\frac{-1}{6})(\,''\,)' & : & Q \\
(+++;--;\ \frac{1}{6}\frac{1}{6}\frac{-1}{6})(\,''\,)' & : & e^c \\
(+++;++;\ \frac{1}{6}\frac{1}{6}\frac{-1}{6})(\,''\,)' & : & \nu^c
\end{array}\right\}\ \boxed{\begin{array}{c}2\times\\ \mathbf{16}\\ \text{Spinor}\end{array}}$$

All the other matter fields in this model turn out to be exactly vector-like under G_{SM}.

[Anomalies have been checked out.]

REFER TO OUR PAPER !!

(hep-ph/0702278)

(hep-ph/0702278)

1. $G_{SM} = SU(3)_c \otimes SU(2)_L \otimes U(1)_Y$ $[\otimes SO(10)]'$

2. $\sin^2\theta_W^0 = \frac{3}{8}$

3. $3 \times \{Q, d^c, u^c, L, e^c, \nu^c\} \subset 3 \times 16$ $(+ 3 \times 10')$

   ↳ {1 from U; 2 " T_4}

   SO(10) spinors

4. $\{H_u, H_d\} \subset 10_h$ → SO(10) vector

   but D/T split

5. All other Matter Fields (Exotics) are vector-like under G_{SM}. → shown to be superheavy

6. $QH_dd^c + LH_de^c \not\subset 10\,\overline{5}\,\overline{5}_h$ or $16\,16\,10_h$

   → $m_d \neq m_e$

7. (exact) R-parity can be consistent with superheavy EXOTICS on a vacuum.

8. 4D N=1 SM becomes 6D N=2 SU(8) above $\mu \gtrsim \frac{1}{R}$.

   $\{H_u, H_d\} \subset$ N=2 gauge sector

Conclusions

- obtained the Partition function in Z_{12-I}
- studied the Mass-shell condi, GSO projector, Wilson line eff. for KK states.
- calculated the threshold corr. to gauge couplings.
  $\longrightarrow$ higher Unif. scale w/ $R \sim 1/M_G$
- proposed a model, in which

4D N=1 SUSY SM $\subset$ 6D N=2 SUSY SU(8)

H_u, H_d $\subset$ N=2 gauge sector

realize "gauge-Higgs Unif."

Thank you!