Higgs mass in the gauge-Higgs unification theory

LCW05 SLAC (3/18/05-3/22/05)

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(tokushima univ.)

Plan of talk

1. Introduction

2. gauge-Higgs unification

-----$SU(3)\times SU(3)$, $SU(6)$ models-----

3. dynamical EW symmetry breaking I

NH, Y. Hosotani, Y. Kawamura and T. Yamashita, Phys.Rev.D70:015010, 2004

NH and T. Yamashita, JHEP 0402:059,2004

4. dynamical EW symmetry breaking II

NH and T. Yamashita, JHEP 0404 (2004) 016

5. Higgs mass and phenomenology

NH, K.Takenaga and T.Yamashita, Phys.Rev.D71:025006,2005
NH, K.Takenaga and T.Yamashita, hep-ph/0411250

6. summary and discussion

1. Introduction

1-1. motivation

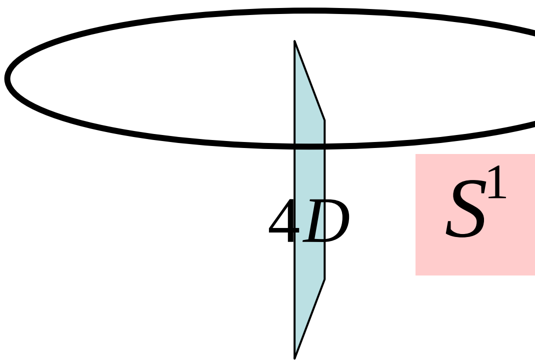
1-2. notation

1-1: motivation

☆ higher dimensional gauge theory:
scalar A_5 in 4D effective theory ← extraD component

→ **identify Higgs field**

ex. $5D\ SU(5)\ GUT$



$A_{M\ (=\underline{0\sim 3},5)}$
μ

$A_5 = \Sigma_{24}$ **Origin of adjoint Higgs which break SU(5)**

dynamics of 5D gauge theory $\rightarrow \langle \Sigma_{24} \rangle$ "Hosotani mech."

☆ hig

sca

→ **identify Hig**

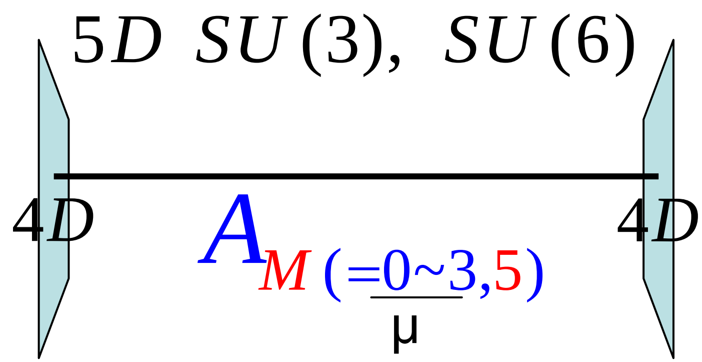
Gauge-Higgs unification

"Higgs doublet" mass is finite! ($\sim$1/R)

5D gauge inv.

ex.

$5D\ \ SU(3),\ \ SU(6)$

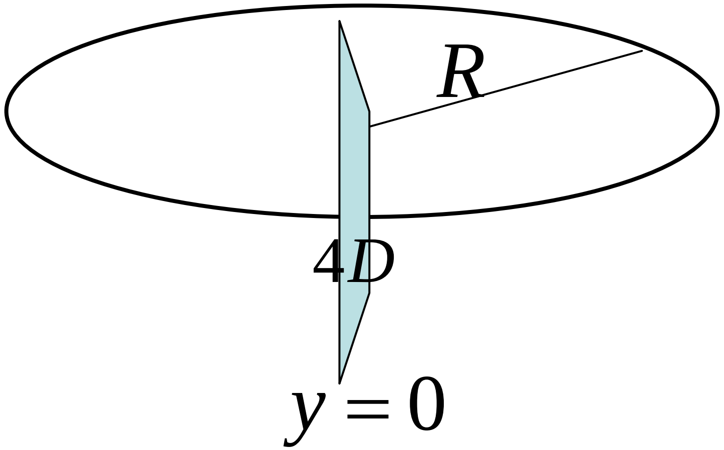


S^1/Z_2

- $H_D \subset A_5(\Sigma_{8,35})$ ⇒ **origin of Higgs doublets**
- $g_5\ \underline{\psi^c_{5D}}_{R}\,A_5\ \underline{\psi_{5D}}_{L}$ ⇒ **origin of Yukawa int.**

1-2: notation

$$(1):\quad M^4 \otimes S^1$$



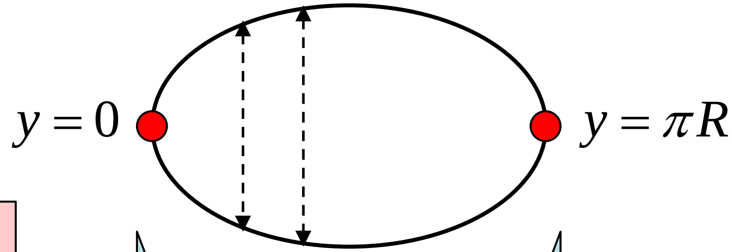
$$\boxed{T:\ \ \phi(x^\mu, y+2\pi R) = T\phi(x^\mu, y)}$$

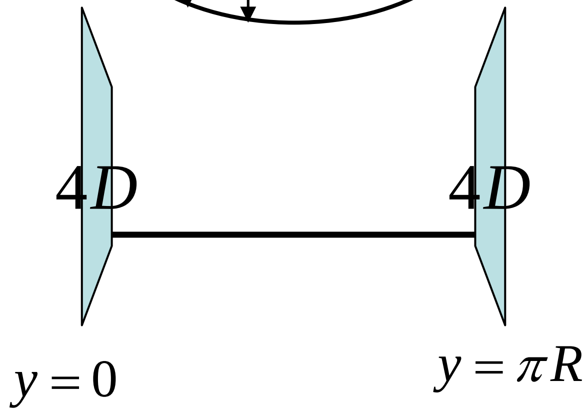
$$[T \in U(N)]$$

$$\phi(x^\mu, y) = \frac{1}{\sqrt{2\pi R}} \sum_{n=-\infty}^{\infty} \phi^{(n)}(x^\mu)\ e^{i\frac{n}{R}y}$$

1-2: notation

$(2): \; M^4 \otimes S^1 / Z^2$ $y = -y$





$$A_\mu(x^\mu,-y) = P A_\mu(x^\mu,y) P$$

$$A_5(x^\mu,-y) = -P A_5(x^\mu,y) P$$

$$\psi_L(x^\mu,-y) = P \psi_L(x^\mu,y)$$

$$\psi_R(x^\mu,-y) = -P \psi_R(x^\mu,y)$$

$$[\psi(x^\mu,-y) = P i \gamma^y \psi(x^\mu,y)]$$

$$5D: \; \gamma^M = (\gamma^\mu, i\gamma^5)$$

$$P: \; \phi(x^\mu,-y) = P\phi(x^\mu,y)$$

$$[P^2 = 1 \;\; \because \phi(y) = P\phi(-y) = P^2\phi(y)]$$

$$\phi_+(x^\mu,y) = \frac{1}{\sqrt{2^{\delta_{n,0}}\pi R}} \sum_{n=0}^{\infty} \phi_+^{(n)}(x^\mu) \, \cos(\frac{ny}{R})$$

$$\phi_-(x^\mu,y) = \frac{1}{\sqrt{\pi R}} \sum_{n=1}^{\infty} \phi_-^{(n)}(x^\mu) \, \sin(\frac{ny}{R})$$

2. gauge-Higgs unification

--- $SU(3)\times SU(3)$ model & $SU(6)$ model---

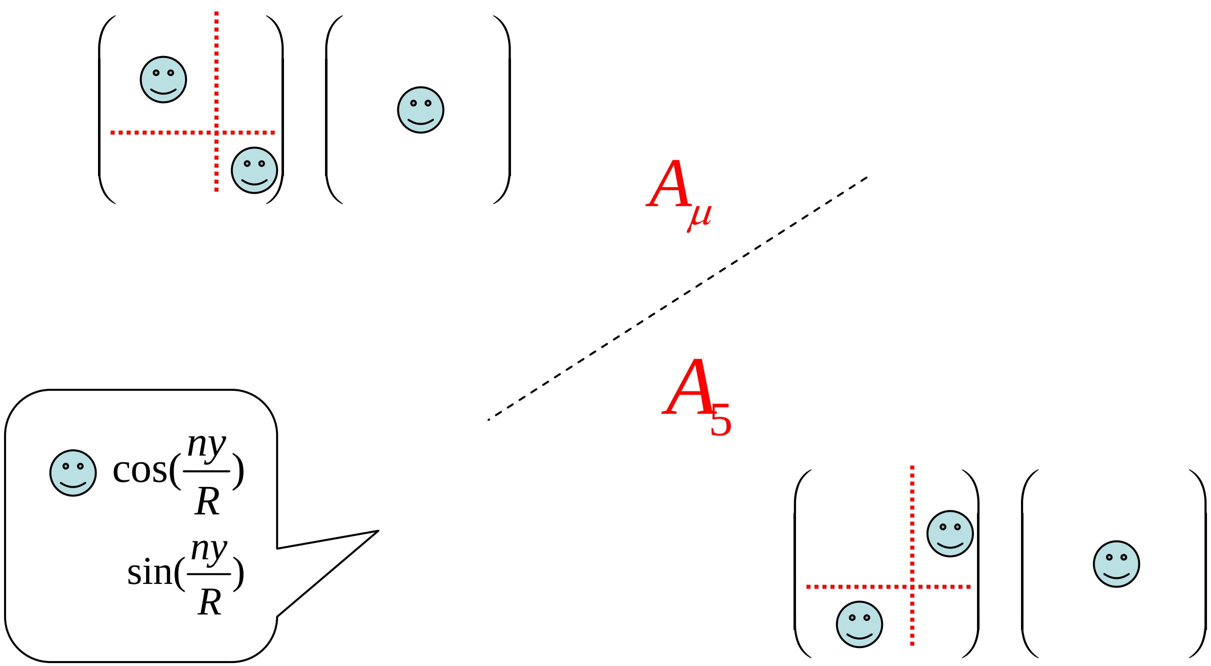
2-1. $SU(3)\times SU(3)$ model
2-2. $SU(6)$ model
2-3. SUSY

2-1. $SU(3)_c \times SU(3)_W$ model

(Kubo,Lim,Yamashita,
Hall,Nomura,Smith,
Burdman,Nomura,….)

$$P = \begin{pmatrix} 1 & & \\ & 1 & \\ & & -1 \end{pmatrix} \qquad T = \begin{pmatrix} 1 & & \\ & 1 & \\ & & 1 \end{pmatrix}$$

in base of
$SU(3)_W \supset SU(2)_L \times U(1)_Y$



2-1. $SU(3)_c \times SU(3)_W$ model

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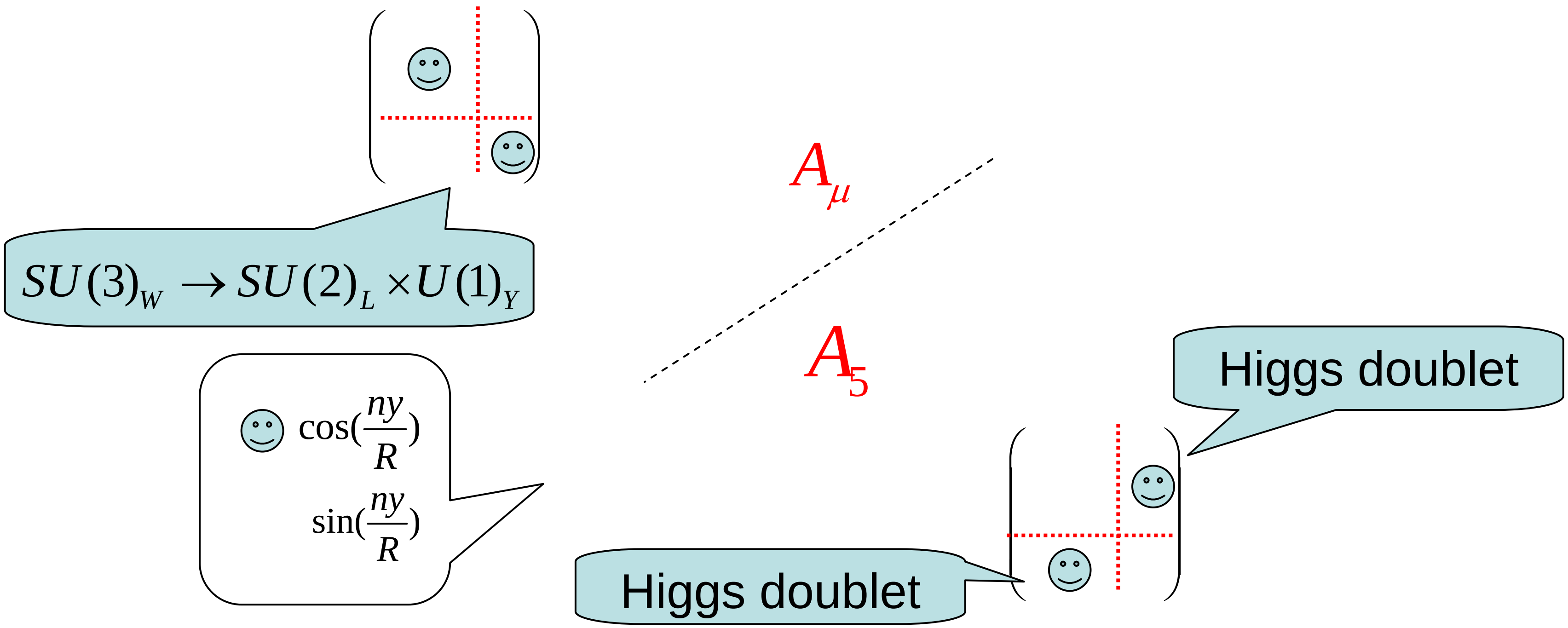
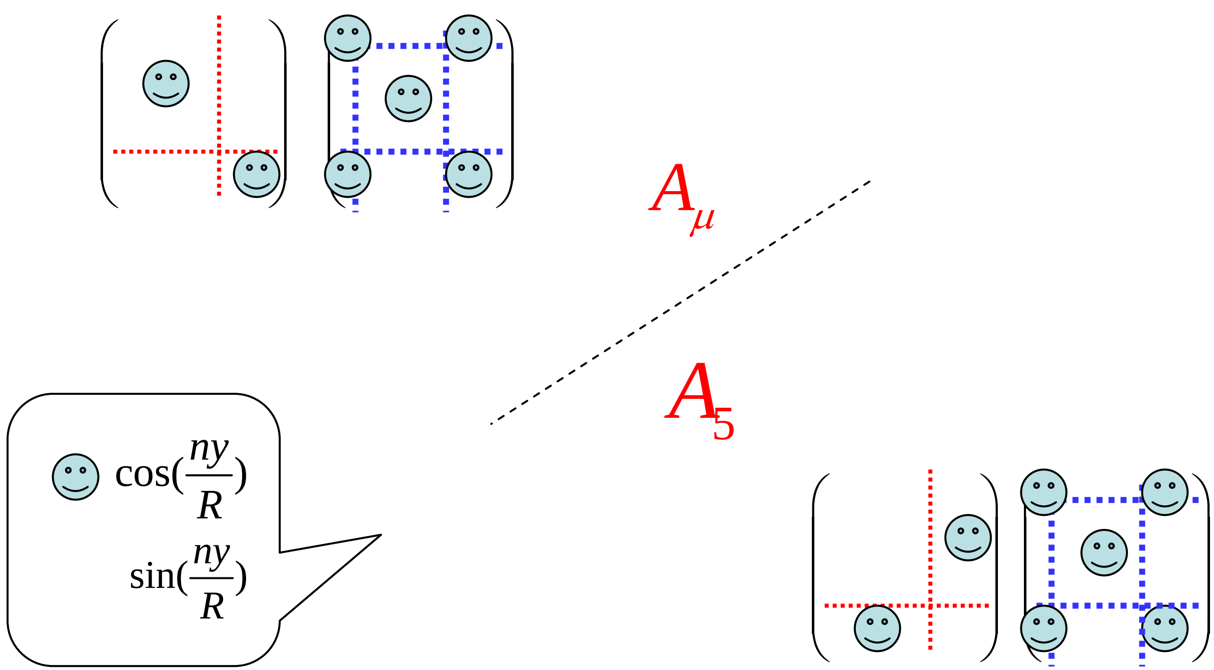


2-2. $SU(6)$ GUT

(Hall,Nomura,Smith,
Burdman,Nomura)

$$P = \begin{pmatrix} 1 &&&&& \\ & 1 &&&& \\ && 1 &&& \\ &&& 1 && \\ &&&& -1 & \\ &&&&& -1 \end{pmatrix} \qquad T = \begin{pmatrix} 1 &&&&& \\ & -1 &&&& \\ && -1 &&& \\ &&& -1 && \\ &&&& 1 & \\ &&&&& 1 \end{pmatrix}$$

in base of $SU(6)$



2-2. $SU(6)$ GUT

(Hall,Nomura,Smith,
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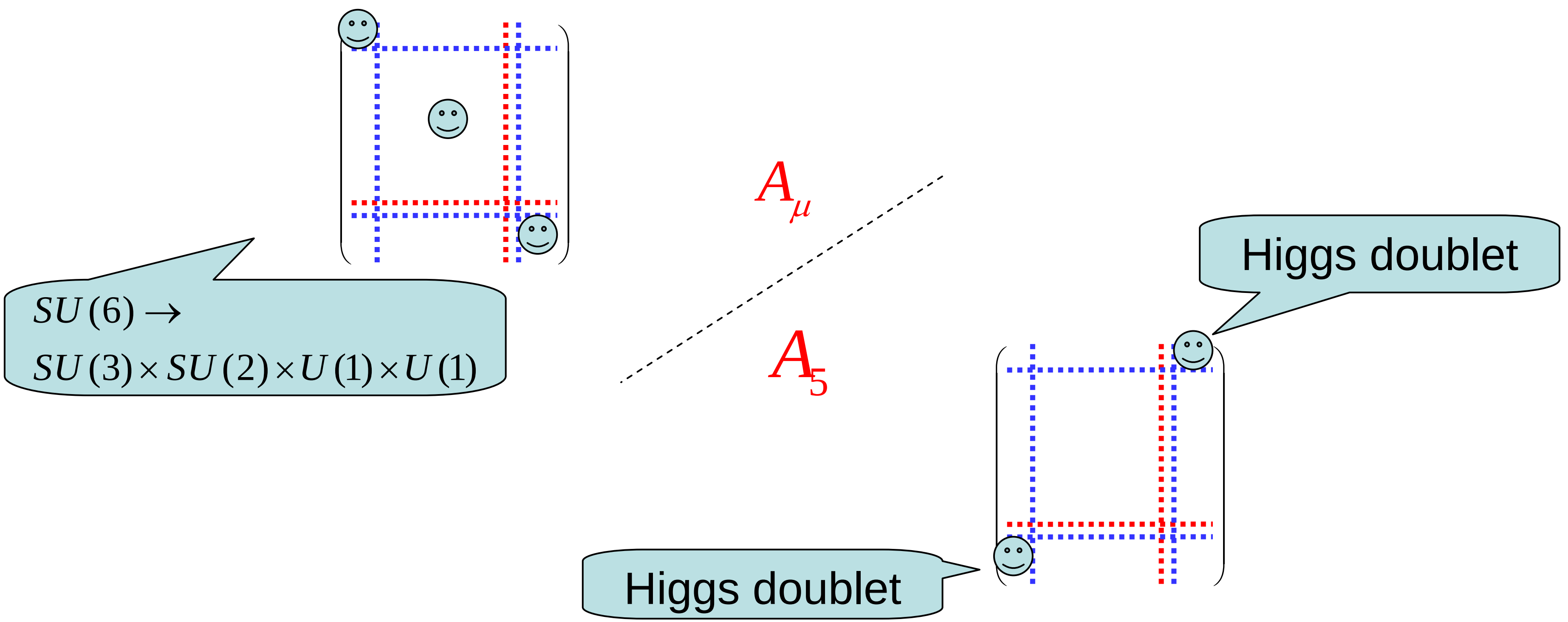
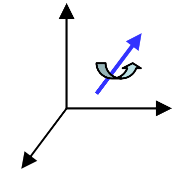
$$P = \left(\begin{array}{cccc|cc} 1 & & & & & \\ & 1 & & & & \\ & & 1 & & & \\ & & & 1 & & \\ \hline & & & & -1 & \\ & & & & & -1 \end{array}\right) \qquad T = \left(\begin{array}{c|ccc|cc} 1 & & & & & \\ \hline & -1 & & & & \\ & & -1 & & & \\ & & & -1 & & \\ \hline & & & & 1 & \\ & & & & & 1 \end{array}\right)$$

in base of $SU(6)$

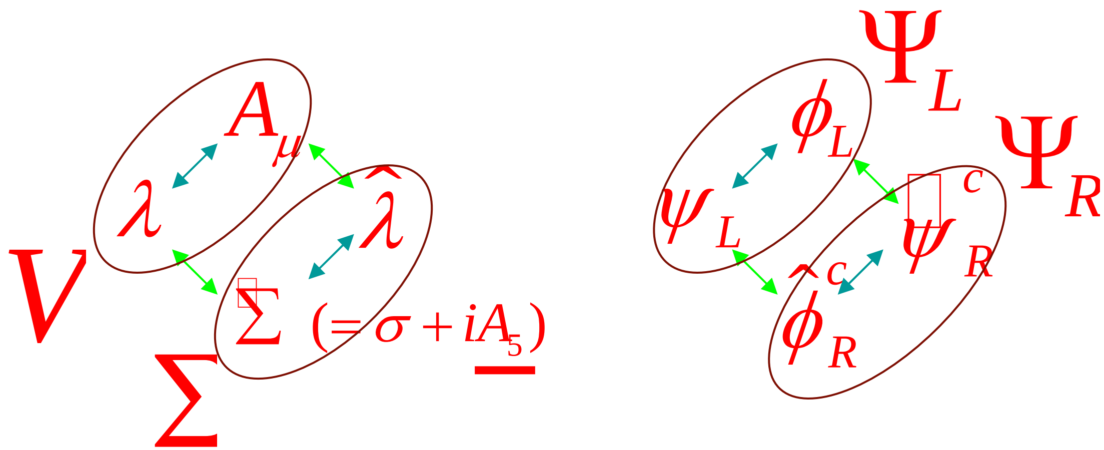


2-3. 5D N=1 SUSY



5D N=1 SUSY

odd dim.=vector-like



⇔ **4D N=2 SUSY**

$$S_{5D}^{hyp.} = \int d^4x dy [\int d^4\theta (\Psi_R e^V \overline{\Psi}_R + \Psi_L e^V \overline{\Psi}_L)$$

$$+\{\int d^2\theta (\underline{\Psi_R} (\partial_y - g_5 \underline{\Sigma}) \underline{\Psi_L}) + h.c.\}]$$

Yukawa int. !!

g ~ y_{top} ~ 0.7 at GUT

3. dynamical EW symmetry breaking I

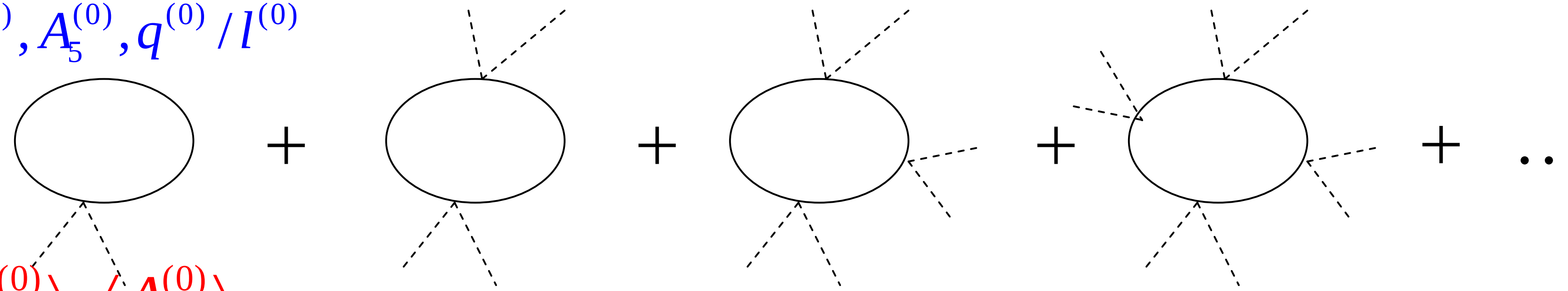
3-1. $SU(3)\times SU(3)$ model
3-2. $SU(6)$ model
3-3. SUSY version

NH, Y. Hosotani, Y. Kawamura and T. Yamashita, Phys.Rev.D70:015010, 2004

NH and T. Yamashita, JHEP 0402:059,2004

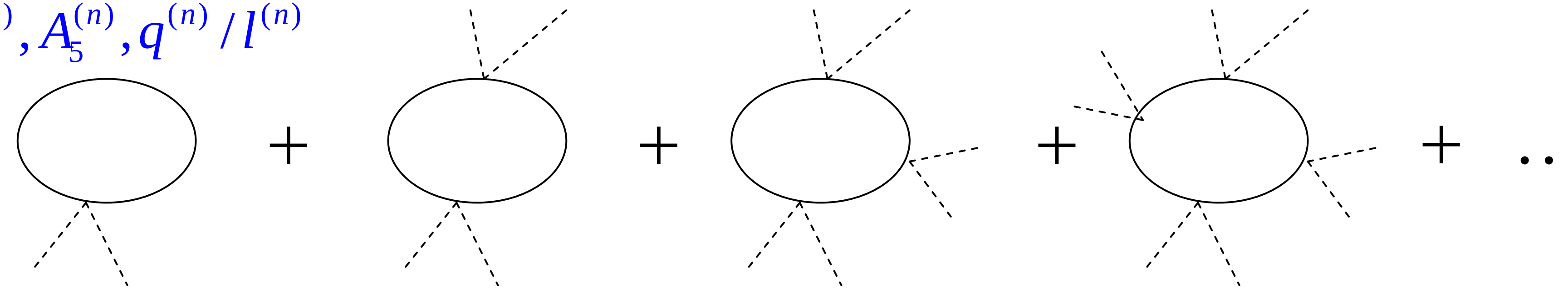
Now let us consider the quantum correction! in theory $A_5^{(0)} \equiv H$

$A_\mu^{(0)}, A_5^{(0)}, q^{(0)} / l^{(0)}$



$\langle A_5^{(0)} \rangle \quad \langle A_5^{(0)} \rangle$

$A_\mu^{(n)}, A_5^{(n)}, q^{(n)} / l^{(n)}$



infinite sum of KK mode **→effective potential,** $V(\langle A_5^{(0)} \rangle)$

(**when SUSY → vanish! →** **Scherk-Schwarz breaking)**

search min. of $V(\langle A_5^{(0)} \rangle)$ → Higgs VEV $\langle A_5^{(0)} \rangle \neq 0, or = 0$

3-1.$SU(3)_{\mathrm{c}} \times SU(3)_{\mathrm{W}}$ model

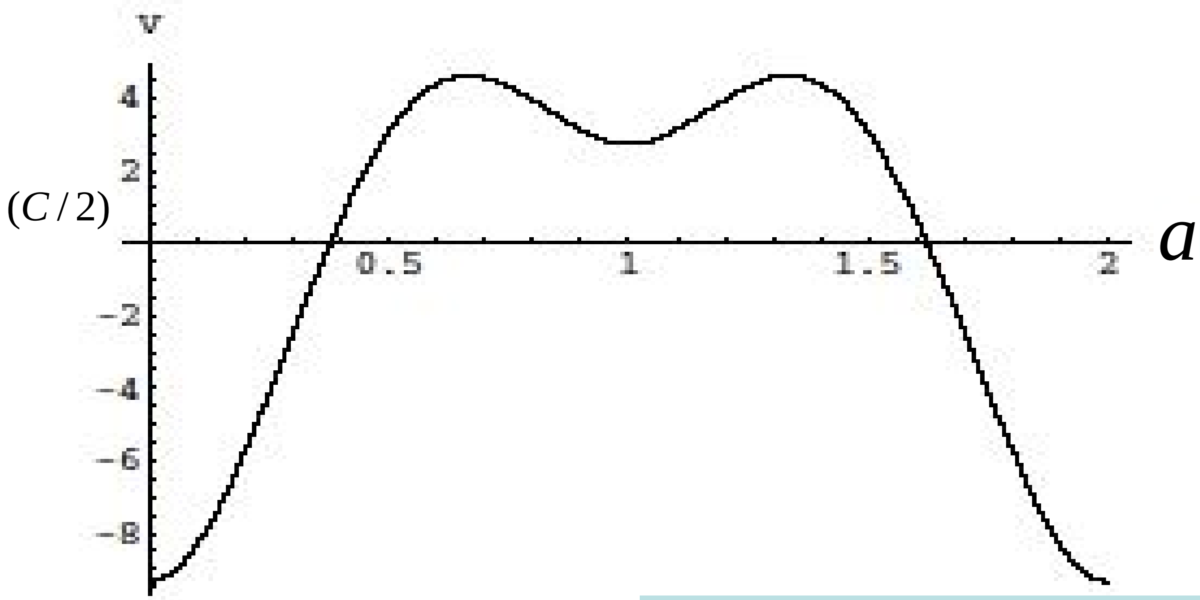
$$\langle A_5^{(0)} \rangle = \frac{1}{2gR} \left(\begin{array}{c|c} & a \\ \hline a & \end{array} \right)$$

a:dim-less

effective potential:

$$V_{eff}(\langle A_5^{(0)} \rangle)$$

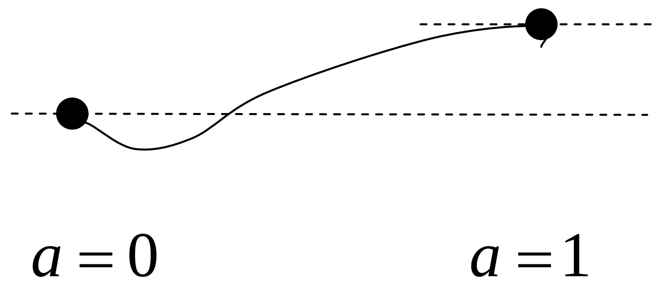
$$V_{eff}^{gauge} = -\frac{3}{2} C \sum_{n=1}^{\infty} \frac{1}{n^5} [\cos(2\pi n a) + \cos(\pi n a)] \qquad C \equiv \frac{3}{64\pi^7 R^5}$$



no sym. breaking!

effective potential: $V_{eff}(\langle A_5^{(0)} \rangle)$

vacuum should be at $0 \le a \ll 1$



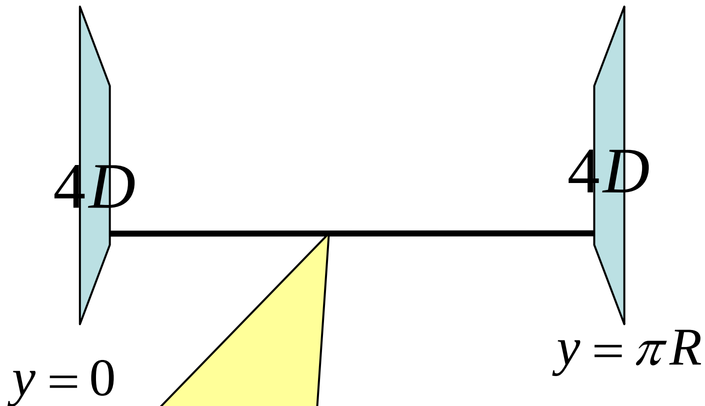
if vacuum is at y=πR

$$
\begin{aligned}
W_C &= \exp\left(ig \int_0^{2\pi R} dy \, \langle \Sigma \rangle \right) \\
&= \exp\left(ig 2\pi R \frac{1}{2gR} \begin{pmatrix} 0 & 0 & 1 \\ 0 & 0 & 0 \\ 1 & 0 & 0 \end{pmatrix} \right) = \begin{pmatrix} -1 & & \\ & 1 & \\ & & -1 \end{pmatrix},
\end{aligned}
$$

$\langle A_5^{(0)} \rangle \sim \frac{1}{R}$ $\quad SU(2) \times U(1) \to U(1) \times U(1)$ at ~ 1/R

Not Good!

effective potential: $V_{eff}(\langle A_5^{(0)} \rangle)$



introduce
extra fields in bulk

$N_a^{(\pm)}, N_f^{(\pm)}, N_s^{(\pm)}$

fermion (adj. & fund.) scalar (fund.)

$$A_\mu(x^\mu,-y) = P A_\mu(x^\mu,y) P$$

$$A_5(x^\mu,-y) = - P A_5(x^\mu,y) P$$

$$\psi_L(x^\mu,-y) = \underline{(\pm)} P \psi_L(x^\mu,y)$$

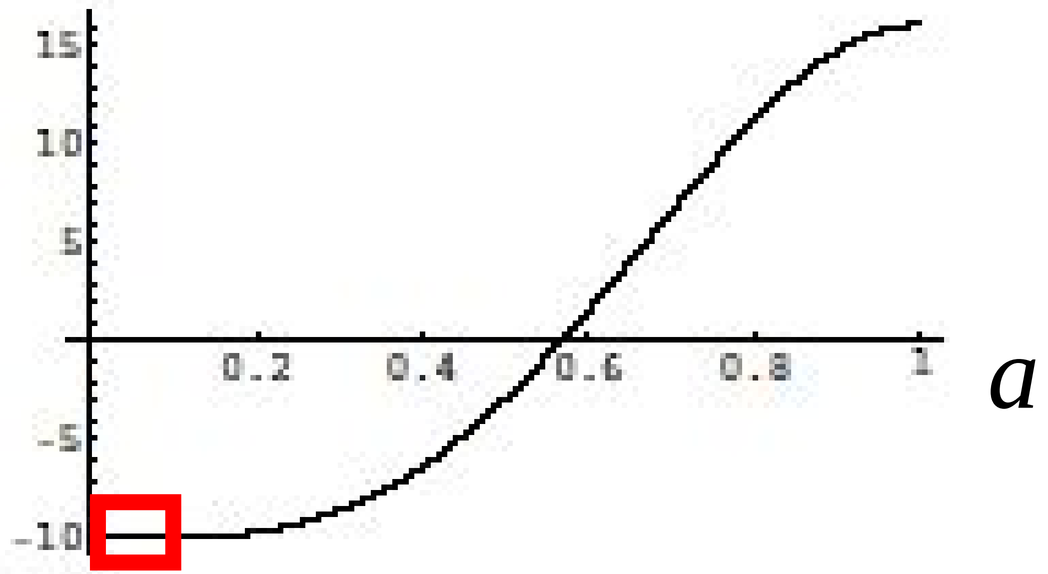
$$\psi_R(x^\mu,-y) = \underline{(\pm)} - P \psi_R(x^\mu,y)$$

$$s(x^\mu,-y) = \underline{(\pm)} s(x^\mu,y)$$

There is d.o.f. of $(\pm)$

$$\begin{aligned} V_{eff}^{m} &= C \sum_{n=1}^{\infty} \frac{1}{n^5} [2N_a^{(+)} \cos(2\pi n a) + 2N_a^{(-)} \cos(2\pi n (a - \frac{1}{2})) \\ &+ (4N_a^{(+)} - N_s^{(+)} + 2N_f^{(+)}) \cos(\pi n a) \\ &+ (4N_a^{(-)} - N_s^{(-)} + 2N_f^{(-)}) \cos(\pi n (a-1))]. \end{aligned}$$

effective potential: $V_{eff}(\langle A_5^{(0)} \rangle) = V_{eff}^{gauge} + V_{eff}^{m}$



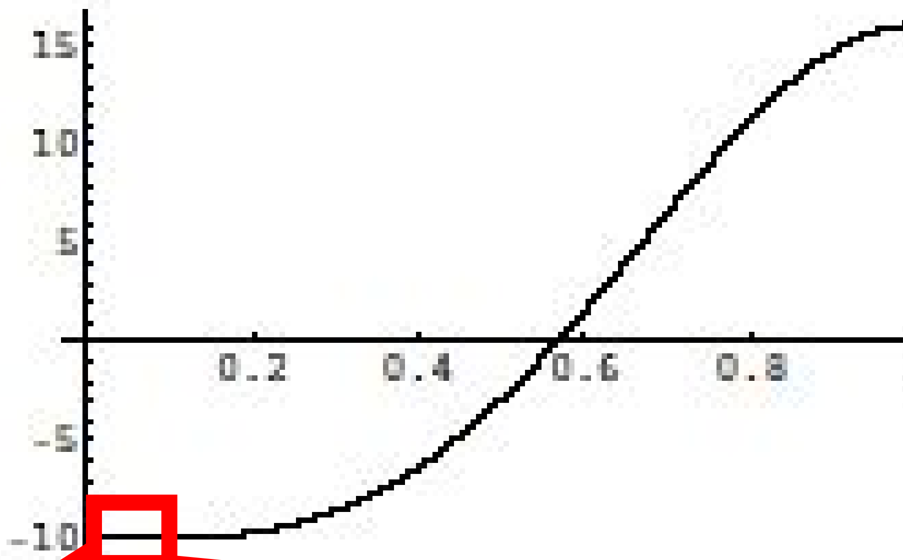
$$N_a^{(+)} = 2, N_f^{(-)} = 8, N_s^{(+)} = 4, N_s^{(-)} = 2, N_a^{(-)} = N_f^{(+)} = 0$$

effective potential: $V_{eff}(\langle A_5^{(0)} \rangle) = V_{eff}^{gauge} + V_{eff}^{m}$

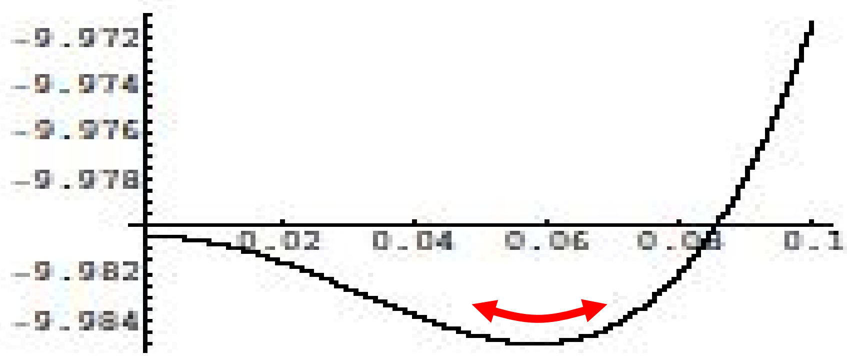
$\frac{1}{R} \sim O(1) \quad TeV$

vev:
O(100)GeV

$SU(2) \times U(1)$
$\downarrow$
$U(1)_{em}$



$N_a^{(+)} = 2,$ ... $= N_f^{(+)} = 0$

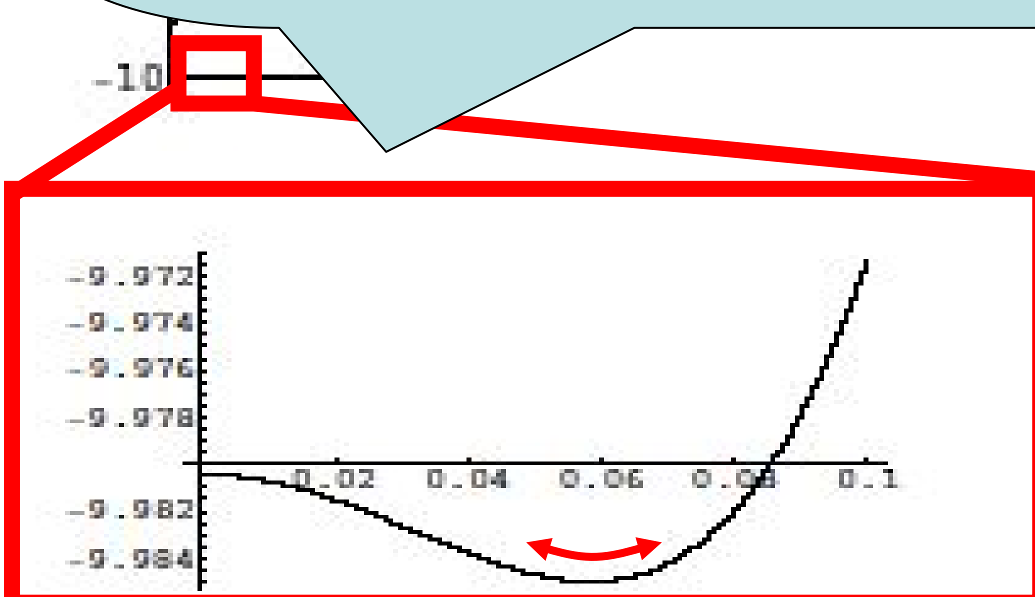


bulk extra field effect is important!

effective potential: $V_{eff}(\langle A_5^{(0)}\rangle) = V_{eff}^{gauge} + \underline{V_{eff}^{m}}$

$$m_{A_5}^2 = (gR)^2 \frac{\partial^2 V_{eff}}{\partial a^2}\Big|_{\min} \sim \left(\frac{O(100)g_4^2}{R} GeV\right)^2$$

$$\frac{g}{\sqrt{2\pi R}} = g_4 \qquad \frac{\langle A_5^{(0)}\rangle}{\sqrt{2\pi R}} = \frac{a}{g_4 R} \sim 246\ GeV$$

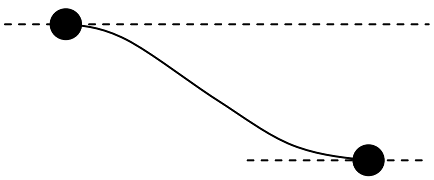


$N_a^{(+)} = 2,$ $= N_f^{(+)} = 0$

bulk extra field effect is important!

3-2. $SU(6)$ GUT

$$P = \begin{pmatrix} 1 &&&&& \\ & 1 &&&& \\ && 1 &&& \\ &&& 1 && \\ &&&& -1 & \\ &&&&& -1 \end{pmatrix} \qquad T = \begin{pmatrix} 1 &&&&& \\ & -1 &&&& \\ && -1 &&& \\ &&& -1 && \\ &&&& 1 & \\ &&&&& 1 \end{pmatrix}$$



$$V_{eff}^{gauge} = -\frac{3}{2} C \sum_{n=1}^{\infty} \frac{1}{n^5} [\cos(2\pi n a) + 2\cos(\pi n a) + 6\cos(\pi n(a-1))]$$

$$V_{eff}^{gauge}(a=0) - V_{eff}^{gauge}(a=1) = 12C \sum_{n=1}^{\infty} \frac{1}{(2n-1)^5} > 0$$

$$\begin{aligned} W_C &= \exp(ig\int_0^{2\pi R} dy \frac{1}{gR} a \frac{\lambda}{2}) \\ &= \exp(ig\frac{1}{gR}\frac{\lambda}{2} 2\pi R) = \begin{pmatrix} -1 &&&&& \\ & 1 &&&& \\ && 1 &&& \\ &&& 1 && \\ &&&& 1 & \\ &&&&& -1 \end{pmatrix} \end{aligned}$$

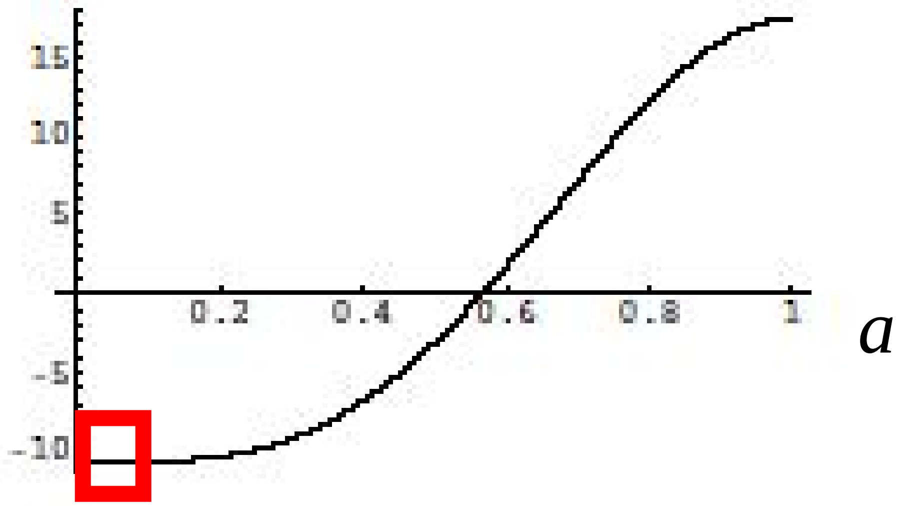
$$SU(2)_L \times U(1)_Y \to U(1)^2$$

$$at \ \langle A_5^{(0)} \rangle \sim \frac{1}{R}$$

not good! → introducing extra fields in bulk

introduce extra bulk fields →

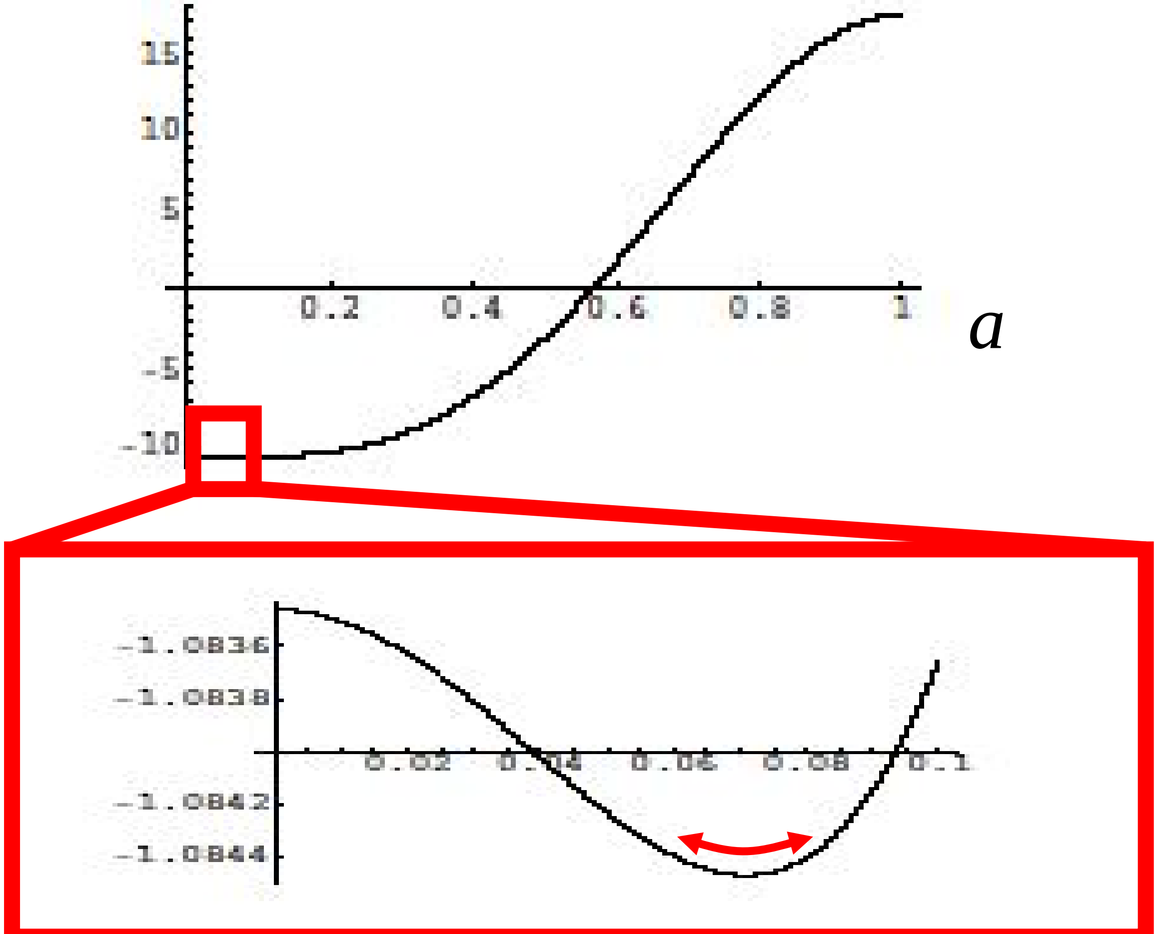
$$\begin{aligned} V_{eff}^{m} &= C\sum_{n=1}^{\infty}\frac{1}{n^5}[2N_a^{(+)}\cos(2\pi n a) + 2N_a^{(-)}\cos(2\pi n(a-\frac{1}{2})) \\ &+(4N_a^{(+)} + 12N_a^{(-)} + 2N_f^{(+)} - N_s^{(+)})\cos(\pi n a) \\ &+(12N_a^{(+)} + 4N_a^{(-)} + 2N_f^{(-)} - N_s^{(-)})\cos(\pi n(a-1))]. \end{aligned}$$



$$N_a^{(+)} = N_f^{(-)} = 2,\ \ other\ Ns = 0$$

introduce extra bulk fields →

$$V_{eff}^{m} = C\sum_{n=1}^{\infty}\frac{1}{n^5}[2N_a^{(+)}\cos(2\pi n a) + 2N_a^{(-)}\cos(2\pi n(a-\frac{1}{2}))$$
$$+(4N_a^{(+)} + 12N_a^{(-)} + 2N_f^{(+)} - N_s^{(+)})\cos(\pi n a)$$
$$+(12N_a^{(+)} + 4N_a^{(-)} + 2N_f^{(-)} - N_s^{(-)})\cos(\pi n(a-1))].$$



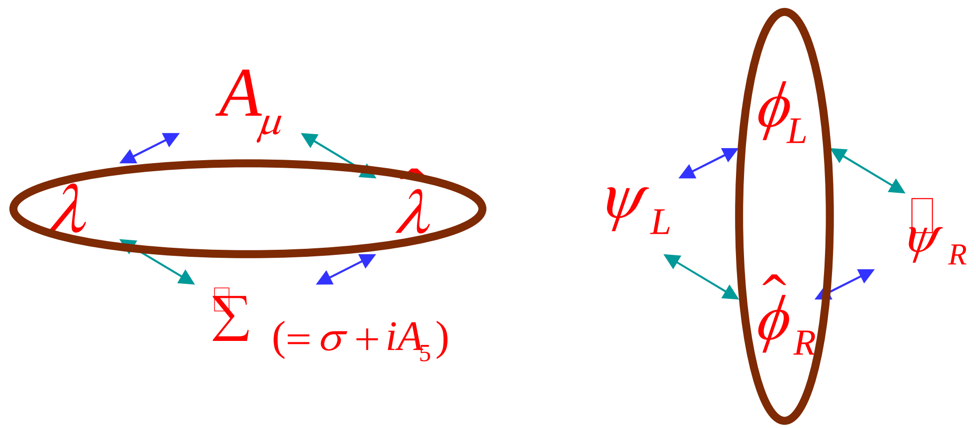
3-3.SUSY version

SUSY must be broken, or V=0!

☆ Scherk-Schwarz SUSY breaking

Imposing different BC for fermion and boson → SUSY br.

twist of $SU(2)_R$



soft mass

$$\rightarrow \quad \frac{\beta}{2R}\lambda\lambda, \quad (\frac{\beta}{R})^2 |\phi|^2$$

☆ soft scalar mass for bulk fields (later)

SUSY version 5D N=1 (→4D N=2)： (Scherk-Schwarz SUSY breaking)

$\beta \sim 0.1$

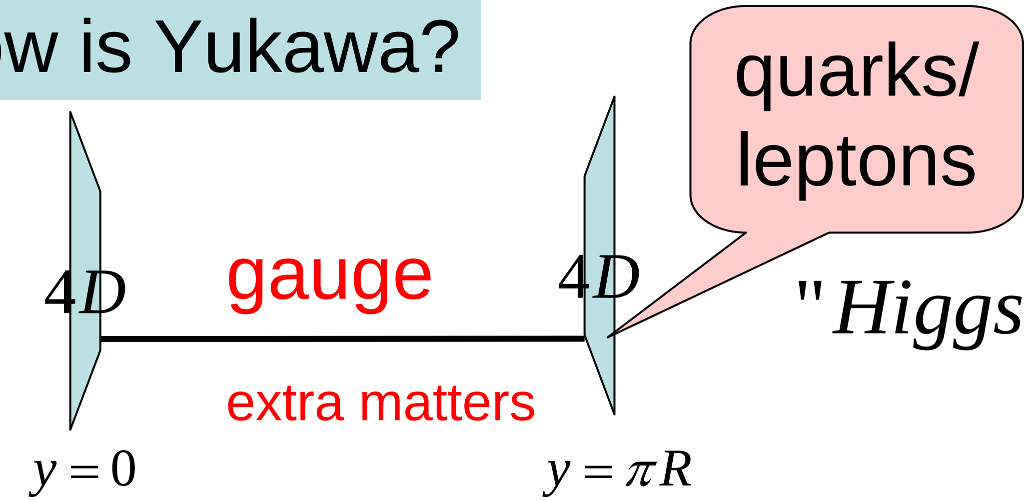
bulk matter: $N_f^{(\pm)}$ fund. & $N_a^{(\pm)}$ adjo. super-feilds

examples:

$$SU(3)\times SU(3): \to N_a^{(+)} = N_a^{(-)} = 2,\ N_f^{(-)} = 4,\ N_f^{(+)} = 0$$

$$SU(6): \to N_a^{(+)} = 2,\ N_a^{(-)} = N_f^{(+)} = 0,\ N_f^{(-)} = 10$$

How is Yukawa?



$$\text{"}Higgs\text{"}:\ P\exp\left(\int A_5\ dy\right)$$

$$(\Sigma \to e^{\Lambda}(\Sigma - \sqrt{2}\partial_y)e^{-\Lambda})$$

quarks/leptons in bulk → $L = [\psi^c_{5D}\, \Sigma_5\ \psi_{5D}]_{\theta^2} + h.c.$

Yukawa from 5D gauge int.

4. dynamical EW symmetry breaking II

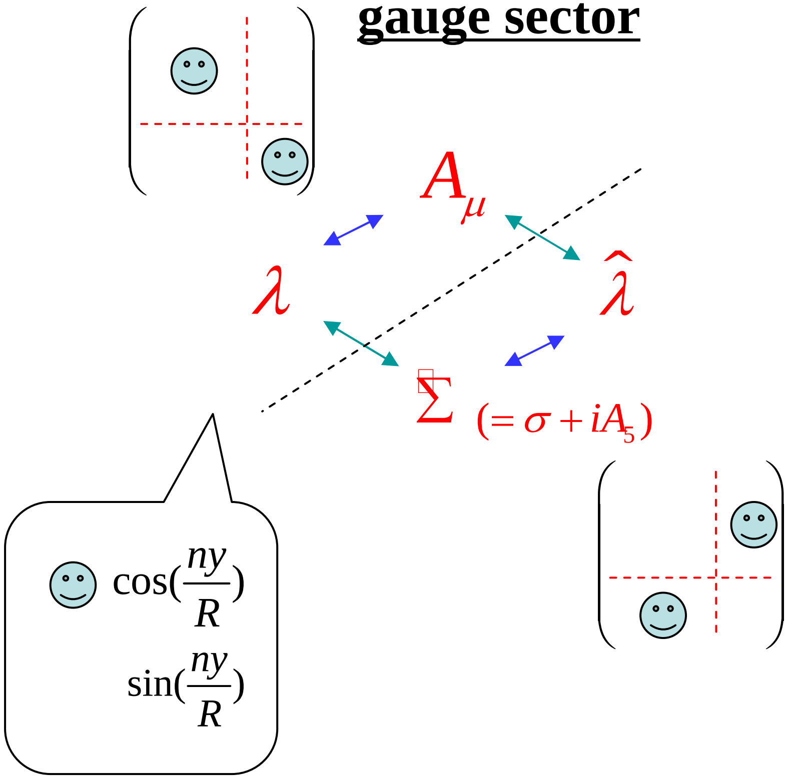
4-1. $SU(3)\times SU(3)$ model
4-2. result

NH and T. Yamashita, JHEP 0404 (2004) 016

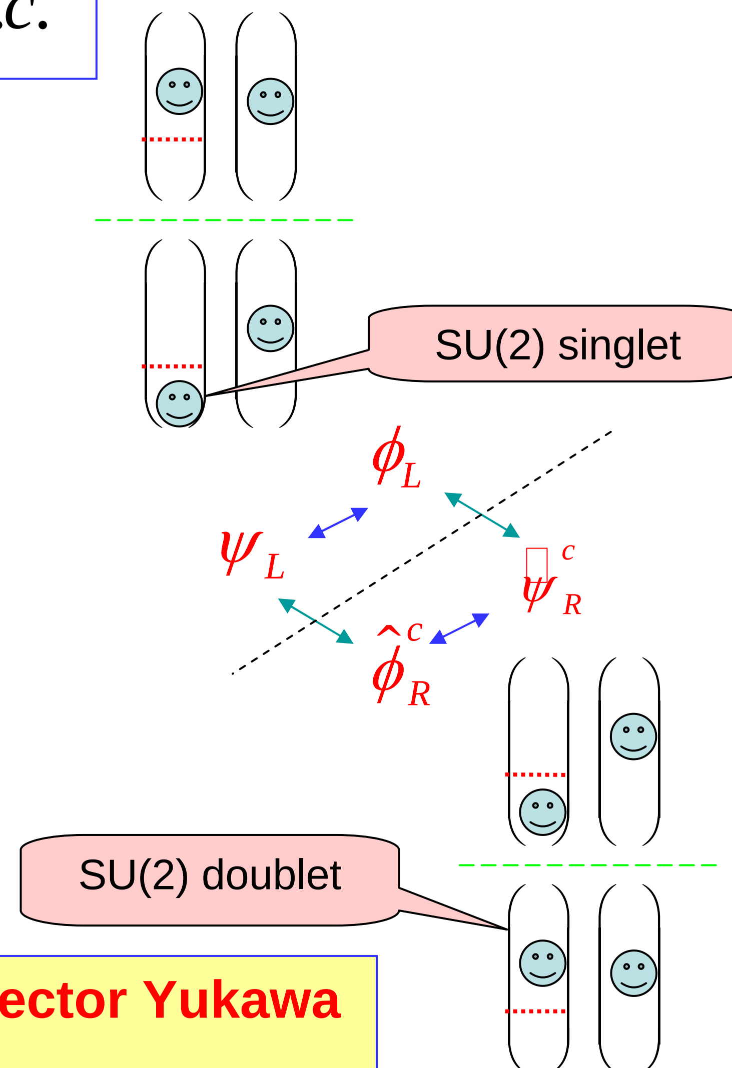
4-1. $SU(3)_c \times SU(3)_W$ model

$$\text{Yukawa} \supset L = [\psi^c_{5D} \Sigma_5 \ \psi_{5D}]_{\theta^2} + h.c.$$

gauge sector



fund. rep. bulk matter



fund. rep. → only down-sector Yukawa
6 → up-sector
10 → charged lepton sector
8 → ν-sector

(Burdman-Nomura)

effective potential: $V(\langle A_5^{(0)} \rangle)$

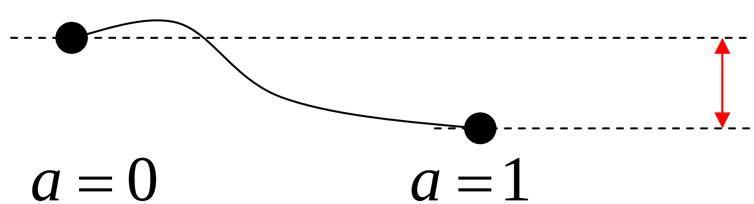
$$V_{\text{eff}}^{q/l} = 2N_g C \sum_{n=1}^{\infty} \frac{1}{n^5}(1-\cos(2\pi n\beta)) \times [3f_u(a) + 3f_d(a) + f_e(a) + f_\nu(a)],$$

$$f_u(a) = \cos(2\pi na) + \cos(\pi na),$$
$$f_d(a) = \cos(\pi na),$$
$$f_e(a) = \cos(3\pi na) + \cos(2\pi na) + 2\cos(\pi na),$$
$$f_\nu(a) = \cos(2\pi na) + 2\cos(\pi na),$$

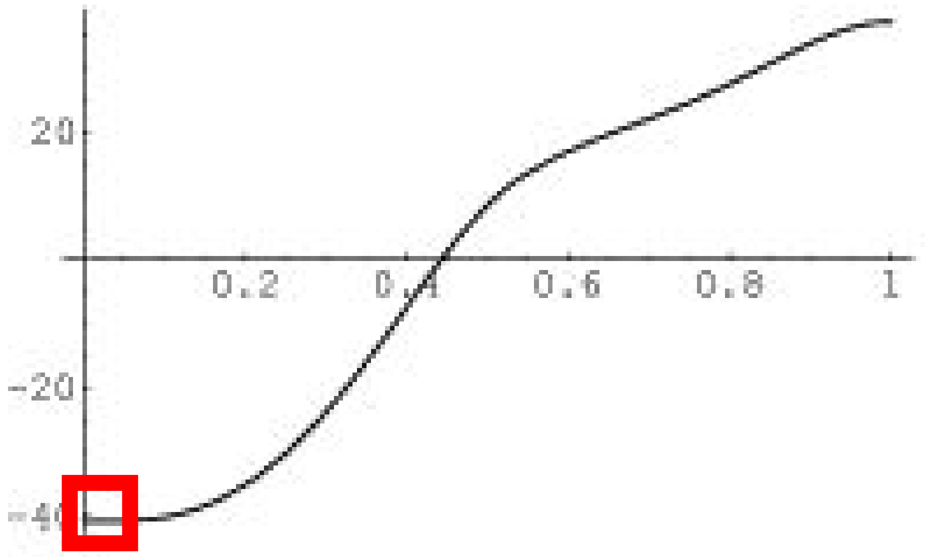
$$V_{\text{eff}} = V_{\text{eff}}^{gauge} + V_{\text{eff}}^{q/l} = 2C \sum_{n=1}^{\infty} \frac{1}{n^5}(1-\cos(2\pi n\beta)) \times [N_g \cos(3\pi na) + (5N_g - 1)\cos(2\pi na) + (10N_g - 2)\cos(\pi na)]$$

$$\underline{V_{\text{eff}}(a=0) - V_{\text{eff}}(a=1)} = 4(11\underline{N_g} - 2)C \sum_{n=1}^{\infty} \frac{1}{(2n-1)^5}(1-\cos(2\pi(2n-1)\beta)).$$

$$> 0$$



effective potential: $V(\langle A_5^{(0)} \rangle)$

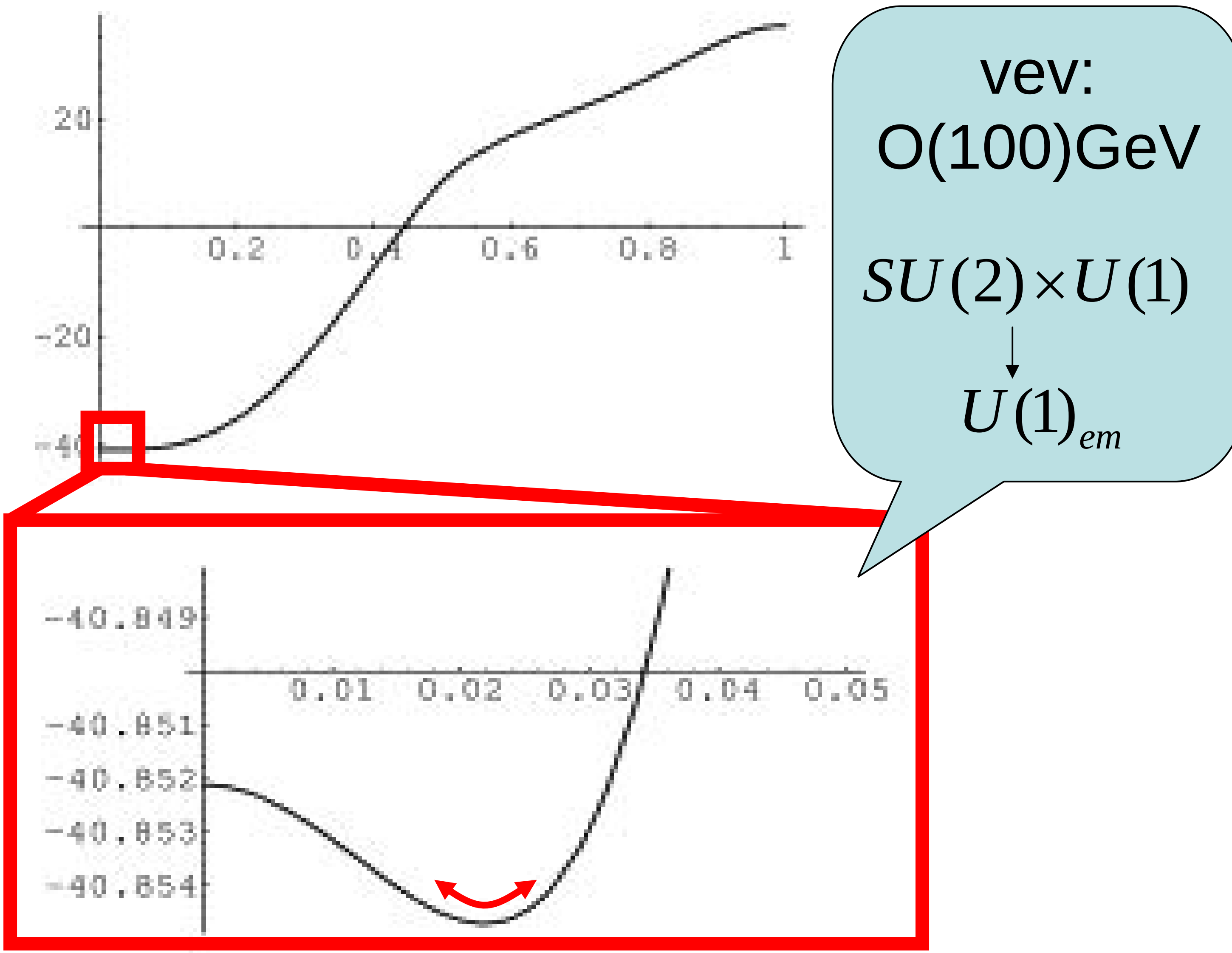


$$N_a^{(+)} = N_f^{(+)} = 0, N_a^{(-)} = 45, N_f^{(-)} = 40 \quad N_g = 3$$

$$\underline{\beta = 0.1,}$$

$$m_{susy} \sim \frac{\beta}{R} \quad \frac{1}{R} \sim O(1) \quad TeV$$

effective potential: $V(\langle A_5^{(0)} \rangle)$



bulk extra field effect is important!

4-2. result

result:

set-up: all 3-generation quarks/leptons in bulk

$$\frac{1}{R} \sim O(1) \quad TeV \qquad m_{susy} \sim \frac{\beta}{R} \qquad \beta = 0.1,$$

examples:

$SU(3)_c \times SU(3)_W$ model

$$N_a^{(+)} = N_f^{(+)} = 0, N_a^{(-)} = 45, N_f^{(-)} = 40$$

$SU(6)$ GUT

$$N_a^{(+)} = N_f^{(+)} = N_a^{(-)} = 0, N_f^{(-)} = 42$$

5. Higgs mass & phenomenology

5-1. Mass spectrum
5-2. soft scalar mass
5-3. 3-point self coupling

NH, K.Takenaga and T.Yamashita, Phys.Rev.D71:025006,2005
NH, K.Takenaga and T.Yamashita, hep-ph/0411250

5-1. Mass spectrum

5D gauge kinetic term→4D Higgs kinetic term

$$2\times\int dy\frac{1}{4}F^{a}_{\mu 5}F^{a\mu 5}=\int dy\frac{1}{2}(\partial A^{a}_{5}+igf^{a}_{bc}A^{b}_{\mu}A^{c}_{5})^{2}=\left|(\partial_{\mu}+ig_{4}W^{\alpha}_{\mu}\frac{\tau^{\alpha}}{2}+i\sqrt{3}g_{4}\frac{B_{\mu}}{2})H\right|^{2}$$

$$A_{5}=\left(\begin{array}{cc|c} & & \frac{A^{4}_{5}+iA^{5}_{5}}{\sqrt{2}} \\ & & \frac{A^{6}_{5}+iA^{7}_{5}}{\sqrt{2}} \\ \hline \frac{A^{4}_{5}-iA^{5}_{5}}{\sqrt{2}} & \frac{A^{6}_{5}-iA^{7}_{5}}{\sqrt{2}} & \end{array}\right) \qquad \begin{pmatrix}\frac{A^{4}_{5}+iA^{5}_{5}}{\sqrt{2}} \\ \frac{A^{6}_{5}+iA^{7}_{5}}{\sqrt{2}}\end{pmatrix}\equiv H/\sqrt{2\pi R} \qquad (g_{4}=\frac{g}{\sqrt{2\pi R}})$$

- However, $g_{Y}=\sqrt{3}g_{2}\rightarrow\sin\theta_{W}=\sqrt{3}/2$, so we assume wall-localized kinetic terms, $\delta(0)\lambda_{0}F^{\mu\nu 2}$, $\delta(\pi R)\lambda_{\pi}F^{\mu\nu 2}$, which do not respect SU(3) symmetry, are dominant as $g_4{}^2 > \lambda^{-1}$, (we take $g_4 \sim 1$), and expect $(W_{\mu},B_{\mu})\rightarrow(\frac{g_{2}}{g_{4}}W_{\mu},\frac{g_{Y}}{\sqrt{3}g_{4}}B_{\mu})$.
- additional U(1)'

$$\sqrt{2\pi R}\,\langle A_{5}\rangle=\frac{a_{0}}{g_{4}R}=v\simeq 246\ GeV$$

$cf:[SU(6):\sin\theta_{W}=\sqrt{3/8}]$

SUSY case

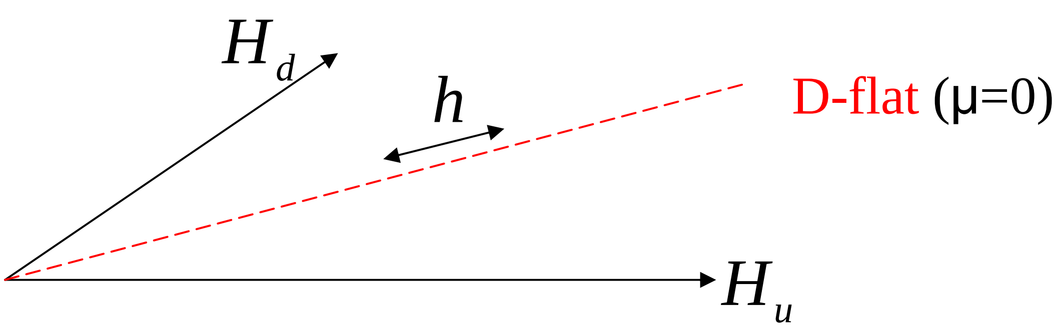
$$\begin{cases} H_u = \dfrac{1}{\sqrt{2}}\left(\langle A_5^4\rangle - \sigma^5 + i(\sigma^4 + A_5^5),\ A_5^6 - \sigma^7 + i(\sigma^6 + A_5^7)\right) \\ H_d = \dfrac{1}{\sqrt{2}}\left(\langle A_5^4\rangle + \sigma^5 + i(\sigma^4 - A_5^5),\ A_5^6 + \sigma^7 + i(\sigma^6 - A_5^7)\right) \end{cases}$$

$A_5^4 : massless\ (h)$	$A_5^5 : \chi^0$	$A_5^{6,7} : \chi^\pm$
$\sigma^4 : massless\ (A)$	$\sigma^5 : M_Z\ (H)$	$\sigma^{6,7} : M_W\ (H^\pm)$

NH, K.Takenaga,T.Yamashita, Phys.Rev.D71:025006,2005

$$\langle \sigma \rangle = 0$$

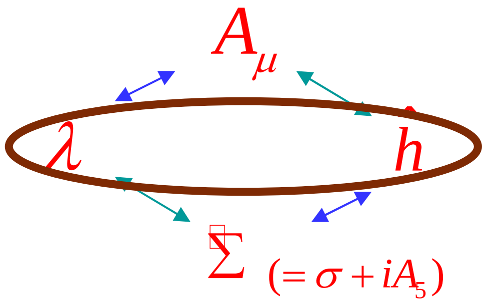
$$\langle A_5^{(0)} \rangle = \frac{1}{2gR}\begin{pmatrix} & a \\ a & \end{pmatrix}$$



$\tan\beta \;\Box\; 1$

Mass Spectrum

twist of $SU(2)_R$



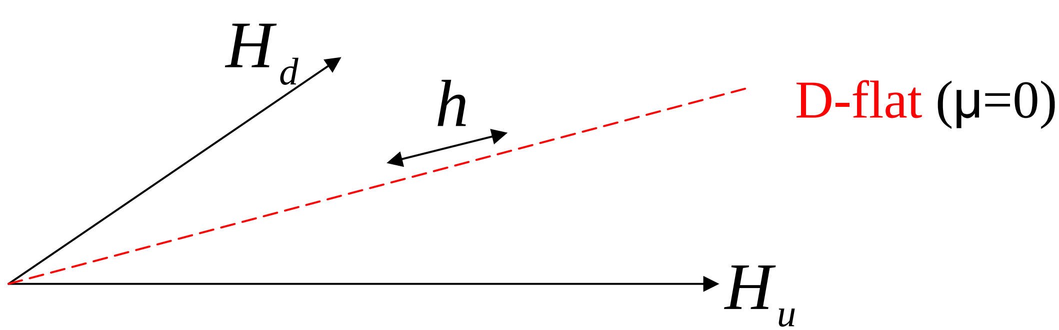
→**gaugino mass ~ higgsino mass** **~ β/R**

(no soft scalar masses)

☆ $h \sim A \sim O(100)GeV, \;\; H \sim H^{\pm} \sim M_{Z,W} + O(100)GeV$

(radiative induced mass ~ O(100)GeV)

☆ gauginos mass~higgsinos mass ~ β/R

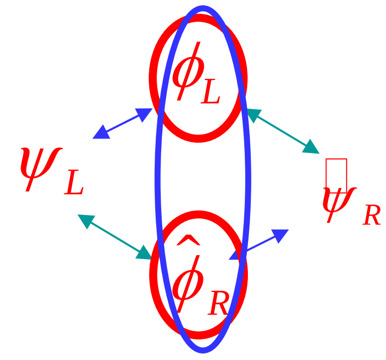


$\tan\beta \sim 1$

5-2. soft scalar mass

- introducing soft scalar mass, m $(z=mR)$ in addition to SS

$SU(3)\times SU(3)$ model



$$V_{eff}^{matter} = 2C\sum_{n=1}^{\infty}\{N_{adj}^{(+)}(I^{(+)}[2a,\beta,z_{adj}^{(+)},n]+2I^{(+)}[a,\beta,z_{adj}^{(+)},n])$$
$$+N_{adj}^{(-)}(I^{(-)}[2a,\beta,z_{adj}^{(-)},n]+2I^{(-)}[a,\beta,z_{adj}^{(-)},n])$$
$$+N_{fnd}^{(+)}I^{(+)}[a,\beta,z_{fnd}^{(+)},n]+N_{fnd}^{(-)}I^{(-)}[a,\beta,z_{fnd}^{(-)},n])\}$$

$$I^{(+)}[a,\beta,z,n]\equiv\frac{1}{n^5}\left(1-\left(1+2\pi zn+\frac{(2\pi zn)^2}{3}\right)e^{-2\pi zn}\cos(2\pi n\beta)\right)\cos(\pi na)$$

$$I^{(-)}[a,\beta,z,n]\equiv\frac{1}{n^5}\left(1-\left(1+2\pi zn+\frac{(2\pi zn)^2}{3}\right)e^{-2\pi zn}\cos(2\pi n\beta)\right)\cos(\pi n(a-1))$$

$N_{adj.}^{(+)}$	$N_{adj.}^{(-)}$	$N_{fnd.}^{(+)}$	$N_{fnd.}^{(-)}$	β	$z_{adj.}^{(+)}$	$z_{adj.}^{(-)}$	$z_{fnd.}^{(+)}$	$z_{fnd.}^{(-)}$	a_0	m_H/g_4^2
2	1	0	2	0.1	0	0	-	0	0.2362	42
2	1	0	2	0.1	0.1	0.1	-	1	0.0097	150

(GeV)

similar effect of large β

$SU(3) \times SU(3)$ model

introducing soft scalar mass, m ($z=mR$)

	$N^{(+)}_{adj.}$	$N^{(-)}_{adj.}$	$N^{(+)}_{fnd.}$	$N^{(-)}_{fnd.}$	β	$z^{(+)}_{adj.}$	$z^{(-)}_{adj.}$	$z^{(+)}_{fnd.}$	$z^{(-)}_{fnd.}$	a_0	m_H/g_4^2
(1)	2	3	0	4	0.05	0.01	0.01	-	0.045	0.0040	164
(2)	2	4	2	6	0.05	0	0	0.05	0.05	0.0037	176
(3)	2	4	0	6	0.025	0.025	0.025	-	0.025	0.0066	129
(4)	2	1	0	2	0.1	0.1	0.1	-	1	0.0097	150
(5)	1	1	0	2	0.01	1	1	-	1	0.0196	125
(6)	2	2	0	2	0.14	0	0	-	0	0.0379	130

$SU(6)$ model

	$N^{(+)}_{adj.}$	$N^{(-)}_{adj.}$	$N^{(+)}_{fnd.}$	$N^{(-)}_{fnd.}$	β	$z^{(+)}_{adj.}$	$z^{(-)}_{adj.}$	$z^{(+)}_{fnd.}$	$z^{(-)}_{fnd.}$	a_0	m_H/g_4^2
(7)	2	0	0	10	0.1	0.05	-	-	0.05	0.0207	139
(8)	2	0	0	6	0.15	0.1	-	-	0.1	0.0268	139
(9)	2	0	0	16	0.04	0	-	-	0.03	0.0021	173
(10)	2	0	0	4	0.07	0.5	-	-	0.5	0.0366	138
(11)	2	0	0	2	0.32	0	-	-	0	0.0594	135

$O(1)$ # bulk fields are OK for DSB

(NH, K.Takenaga and T.Yamashita, hep-ph/0411250)

5-3. 3-point self coupling

☆ higher order operators

$$V \;\Box\; \cos a \;\Box\; a^n = (g_4 RH)^n$$

$g_4 R \;\Box\;$ a few TeV → suppression scale → suppressed enough

☆ effective 3-point coupling

$$\lambda \equiv \frac{3g_4^2}{32\pi^6 R} \frac{\partial^3 V}{\partial a^3}\bigg|_{a=a_0}$$

deviation from SM $\Box\lambda = \dfrac{\lambda - \lambda_{SM}}{\lambda_{SM}}, \quad \lambda_{SM} = \dfrac{3m_h^2}{v}$

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
$\Delta\lambda(\%)$	-8.6	-8.3	-14.0	-10.2	-3.1	-13.7	-12.0	-12.0	-7.6	-11.2	-12.7

tend to be small comparing to SM

6. summary and discussion

summary

gauge-Higgs unification=origin of Higgs doublets & Yukawa int.

- $H_D \subset A_5$ → doublet Higgs
- $\psi^c_{5D} A_5 \, \psi_{5D}$ → Yukawa ints.

Higgs mass is finite! (5D gauge invariance)

1 loop effective potential of Higgs doublets (A_5)

in $SU(3) \times SU(3)$ model & $SU(6)$ GUT (q/l: blane & bulk)

↓

EW DSB can be possible by extra bulk matters (suitable # & rep.)

☆ h □ A □ $O(100)GeV$, H □ $H^{\pm}$ □ $M_{Z,W} + O(100)GeV$

(**radiative induced mass ~ O(100)GeV)**

☆ extra bulk fields ~ O(100) GeV

☆ $\tan\beta$ □ 1

☆ gauginos mass~higgsinos mass ~ β/R

☆ SUSY br. gaugino ⇔ higgsino

(Burdman,Nomura)

$$M_{\lambda} = \tilde{m},\ \ \mu = -\tilde{m},\ \ \tilde{m}^{2}_{h_u h_d} = -\tilde{m}^{2},\ \ B = 0$$ at tree level at 1/R

radiative br. is possible?

investigate by including gravity effects

another approach of EW symmetry breaking in gauge-Higgs unification:

(Choi, N.H., Jeong, Okumura, Shimizu, Yamaguchi, JHEP 0402:037,2004)

problems

(1): Winberg angle

←• small brane-localized Higgs kinetic term

bulk gauge coupling > brane-localized g.c.

(g_4 ~ $O(1)$, $(M_*R)^{1/2} \gg 1$ ($M_* \gg 1/R$))

• additional $U(1)$'

(2): proton decay suppression for TeV scale compactification

← $U(1)_B$

(3): general soft masses in SUSY etc

← how to calculate deviation from $\tan\beta = 1$ (D-flat) ?

related studies

☆ 5D E_6, E_7 GUTs on S^1/Z_2

E_6: bulk matters ⇒ **adjoint & fund.**

E_7: bulk matters ⇒ **adjoint**

fermion mass hierarchy & flavor mixings← wall-localized extra fields effects

(NH and Y. Shimizu, Phys.Rev.D67:095001,2003, Erratum-ibid.D69:059902,2004)