ORBIFOLD BREAKING OF LEFT-RIGHT GAUGE SYMMETRY

ICHEP 2002, SESSION 12

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: WORK DONE IN COLLABORATION WITH Y. MIMURA, hep-ph/0203126 (TO APPEAR IN PLB)

: INTRODUCTION TO ORBIFOLD SYMMETRY BREAKING (INTERESTING ALTERNATIVE TO HIGGS MECHANISM)

: EXAMPLES OF GAUGE SYMMETRY BREAKING

: APPLY TO BREAKING OF LEFT-RIGHT SYMMETRY ON $S^1/Z_2 \times Z_2'$ ORBIFOLD

: PHENOMENOLOGICAL IMPLICATIONS

→ OUR WORK

: CONSIDER ONLY <u>ONE</u> EXTRA DIMENSION AT THE <u>TEV^{-1}</u> SCALE

INTRODUCTION

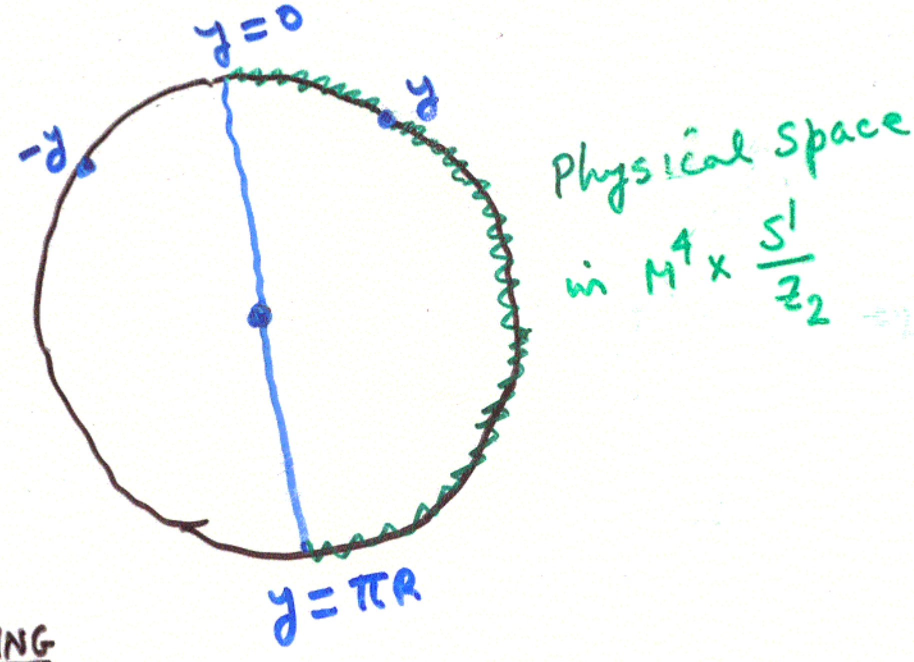
STRING MOTIVATED
5-D FIELD THEORY : (x_μ, y) , $\mu = 0,1,2,3$

$\Phi(x_\mu, y)$: Compactify y on a circle, S^1

$5D \longrightarrow M_4 \times S^1$

: Z_2 symmetry : $y \to -y \Rightarrow \frac{S^1}{Z_2}$ orbifold

$y = 0$ }
$y = \pi R$ } Two fixed points



SYMMETRY BREAKING

$$\Phi = \begin{pmatrix} \phi_1 \\ \phi_2 \\ \vdots \\ \phi_N \end{pmatrix}, \qquad \text{under } Z_2: \quad \Phi(x, -y) = P\,\Phi(x, y)$$

P = an $(N\times N)$ matrix,
$P^2 = I$, also $P^\dagger P = I$

: Z_2- inv. does not require $P = I$ or $-I$

$\Rightarrow$ Symmetry can be broken by giving different components of Φ different Z_2- parity.

ORBIFOLD BREAKING OF

EXAMPLE: LOCAL (gauge) SYMMETRY

idea: give different components of the gauge fields diff. transformation property under Z_2.

Those even under Z_2 $\Rightarrow$ have zero mode

Those odd under Z_2 $\Rightarrow$ no zero mode

$$\Rightarrow \quad G \xrightarrow[\text{to}]{\text{breaks}} G'$$

Example: consider $SU(2)$ gauge symmetry

$$T_1 = \frac{1}{2}\begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}, \quad T_2 = \frac{1}{2}\begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}, \quad T_3 = \frac{1}{2}\begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$$

$A_a, \quad a = 1, 2, 3$

$$A_M(x, y) = T_a A_{Ma}(x, y), \quad M = \mu, 5$$

$$\mathcal{L}_5 = -\frac{1}{2} \operatorname{Tr}(F_{MN} F^{MN})$$

under Z_2:

$$A_\mu(x,y) \to A_\mu(x,-y) = P\, A_\mu(x,y)\, P^{-1}$$

$$A_5(x,y) \to A_5(x,-y) = -P\, A_5(x,y)\, P^{-1}$$

choose $P = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$, then

$$PT_1P^{-1} = -T_1, \quad PT_2P^{-1} = -T_2, \quad PT_3P^{-1} = T_3$$

Now, $A_\mu(x,y) = T_a\, A_{\mu a}(x,y)$

Thus, Lagrangian to remain inv., we must have

$A_{\mu 1,2}(x,-y) = -A_{\mu 1,2}(x,y) \Rightarrow$ <u>no</u> massless mode

$A_{\mu 3}(x,-y) = A_{\mu 3}(x,y) \Rightarrow$ <u>have</u> massless mode

SPECTRUM UPON COMPACTIFICATION ON S^1

States	mass	#
$\vdots$		
$A^{(2)}_{\mu a}$	$2/R$	3
$A^{(1)}_{\mu a}$	$1/R$	3
$A^{(0)}_{\mu a}$, $a=1,2,3$	0	3

SPECTRUM UPON COMPACTIFICATION ON S^1/Z_2

States	mass	#
$\vdots$		
$A^{(2)}_{\mu a}$	$2/R$,	3
$A^{(1)}_{\mu a}$, $a=1,2,3$	$1/R$,	3
$A^{(0)}_{\mu 3}$	0,	1

$$SU(2) \xrightarrow[S^1/Z_2]{\text{broken to}} U(1)$$

What happens to $A_5(x,y)$?

$$A_5(x,y) = T_a A_{5a}$$

$$A_5(x,-y) = -P A_5(x,y) P^{-1} \Rightarrow A_5^{1,2}(x,-y) = A_5^{1,2}(x,y)$$

$$A_5^3(x,-y) = -A_5^3(x,y)$$

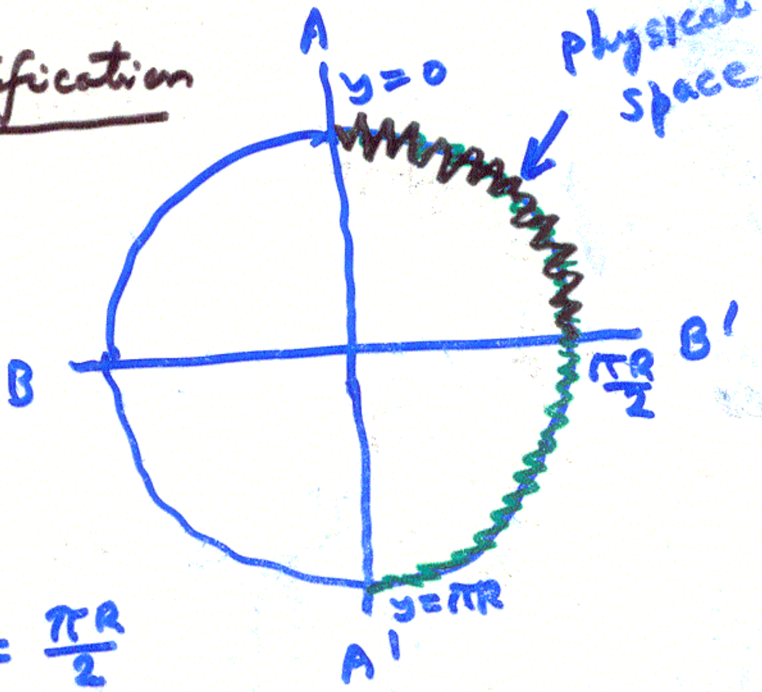
$\Rightarrow A_5^{1,2}(x,y)$: has massless mode

$A_5^3(x,y)$: no massless mode

scalar massless particle

We can make massless modes disappear ~~from~~ the Spectra by choose $\frac{S^1}{Z_2 \times Z_2'}$ orbifold.

$\frac{S^1}{Z_2 \times Z_2'}$ orbifold compactification



Z_2: $y \to -y$

Z_2' : $y' \to -y'$

where $y' \equiv y + \frac{\pi R}{2}$

Fixed points : $y = 0$

and, $y = \frac{\pi R}{2}$

under S^1/Z_2 : States $\Rightarrow +, -$

under $S^1/Z_2 \times Z_2'$: States $\Rightarrow (++, -+, +-, --)$

A_μ^3 , $A_\mu^{1,2}$, $A_5^{1,2}$, A_5^3

SUPERSYMMETRY BREAKING

Basic idea : assign different $Z_2 \times Z_2'$ parity to the superpartners leading to splitting of mass degeneracy

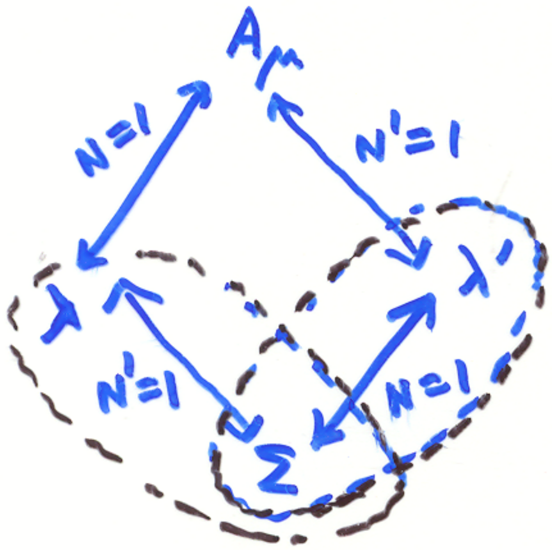
5D SUSY :

Vector multiplet : $V(A_M, \lambda, \lambda', \sigma)$,

$A_M \to A_\mu, A_5$

$$\frac{A_5 + i\sigma}{\sqrt{2}} = \Sigma$$

Equivalent to 4D vector multiplet $V(A_\mu, \lambda)$ and a chiral multiplet in the adjoint representation, (λ', Σ).



S^1 : all have massless mode

$\frac{S^1}{Z_2}$: $V(A_\mu, \lambda)$: + $\Rightarrow$ massless mode

(λ', Σ) : − $\Rightarrow$ no massless mode

$\Rightarrow$ Breaks $N' = 1$ SUSY

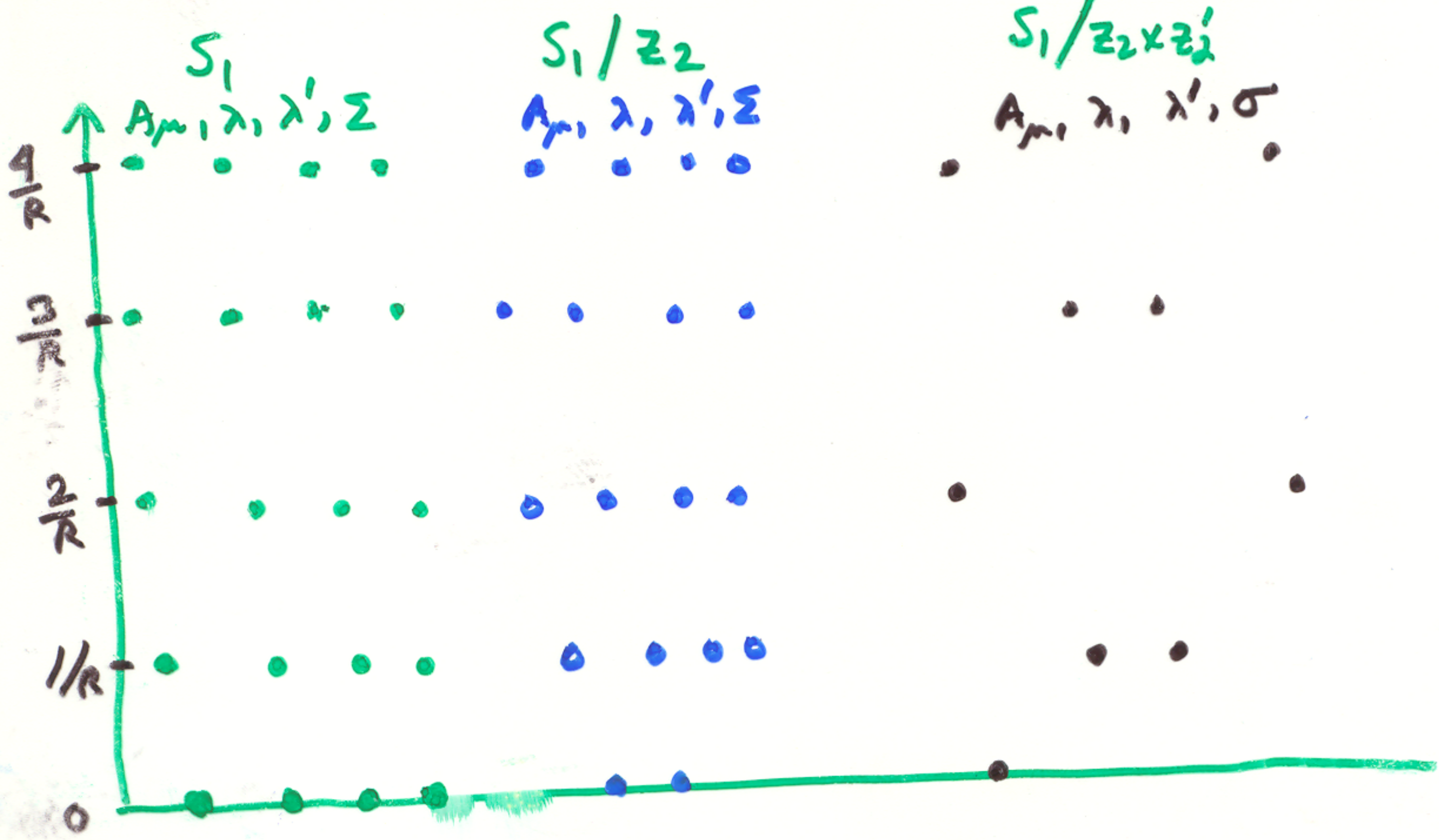
$\frac{S^1}{Z_2 \times Z_2'}$:

$A_\mu = (+, +) \to$ massless mode

$$\left.\begin{aligned} \lambda &= (+, -) \\ \lambda' &= (-, +) \\ \Sigma &= (-, -) \end{aligned}\right\} \to \text{no massless mode}$$

$\Rightarrow$ Breaks <u>both</u> supersymmetry

SPECTRUM



S_1
$A_\mu, \lambda, \lambda', \Sigma$
S_1/Z_2
$A_\mu, \lambda, \lambda', \Sigma$
$S_1/Z_2 \times Z_2'$
$A_\mu, \lambda, \lambda', \sigma$
$\frac{4}{R}$
$\frac{3}{R}$
$\frac{2}{R}$
$1/R$
0

ORBIFOLD BREAKING OF LEFT–RIGHT GAUGE SYMMETRY

(Y. Mimura + S. Nandi)
hep-ph/0203126

$$SU(2)_L \times SU(2)_R \times U(1)_{B-L}$$

g_L $\quad$ g_R $\quad$ g'

$$L \leftrightarrow R \;:\; g_L = g_R \equiv g$$

Two couplings : g, g'

$$Q = T_{3L} + \underbrace{T_{3R} + \frac{B-L}{2}}_{\equiv \frac{Y}{2}}$$

$$(W_L^{+-}, W_{3L}),\ (W_R^{\pm}, W_{3R}),\ B$$

$$SU(2)_L \times SU(2)_R \times U(1)_{B-L}$$

$$\xrightarrow[(v)]{M_{W_R}} SU(2)_L \times U(1)_Y \xrightarrow[(\kappa)]{W_L} U(1)_{EM}$$

Higgs $\qquad\qquad$ Higgs

$(\chi_L$ and $\chi_R)$ $\qquad\qquad$ $\phi(2,2,0)$

$(\frac{1}{2},0,1)$ $\quad$ $(0,\frac{1}{2},1)$ $\qquad\qquad$ $\langle\phi\rangle = \begin{pmatrix} \kappa & 0 \\ 0 & \kappa' \end{pmatrix}$

$\langle\chi_R\rangle = \begin{pmatrix} 0 \\ v \end{pmatrix}$

or, triplets $\langle\Delta_R\rangle = \begin{pmatrix} 0 & 0 \\ v & 0 \end{pmatrix}$ $\qquad\qquad$ $M_{W_L} \sim \frac{g}{\sqrt{2}}\sqrt{\kappa^2+\kappa'^2}$

$M_{W_R} \sim \frac{gv}{\sqrt{2}}$ $\qquad\qquad$ If $v \gg (\kappa, \kappa')$
$M_{W_R} \gg M_{W_L}$

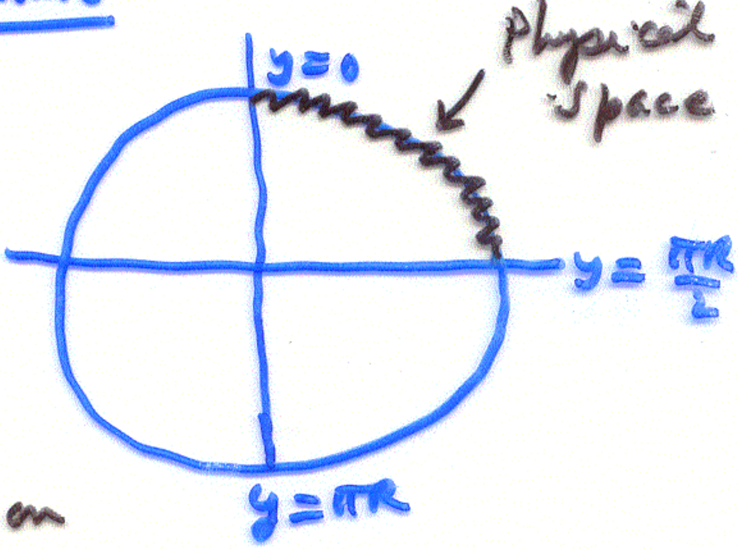
Left-right gauge symmetry

$\Rightarrow$: Natural explanation of parity violation at low energy ($M_{W_R} \gg M_{W_L}$)

: non-vanishing of ν-masses

LEFT-RIGHT GAUGE SYMMETRY IN 5D AND ORBIFOLD BREAKING

$\dfrac{S^1}{Z_2 \times Z_2'}$ orbifold



Assume

: Gauge & Higgs fields propagate into bulk

: Fermions are confined on the 4D wall at $y=0$

Symmetry Breaking :

$$
\begin{array}{c}
SU(2)_L \times SU(2)_R \times U(1)_{B-L} \\
\big\downarrow \text{ orbifold compactification, } \tfrac{1}{R} \\
SU(2)_L \times U(1)_R \times U(1)_{B-L} \\
\big\downarrow \text{ Higgs } \chi_R(1,2,\tfrac{1}{2}),\ v \\
SU(2)_L \times U(1)_Y \\
\big\downarrow \text{ Higgs. } \Phi(2,2,0),\ \kappa \\
U(1)_{EM}
\end{array}
$$

We impose the following transformation for the 5D gauge fields:

$$Z_2: \quad V_\mu(x,-y) = P\, V_\mu(x,y)\, P^{-1}$$

$$V_5(x,-y) = -P\, V_5(x,y)\, P^{-1}$$

$$Z_2': \quad V_\mu(x,-y') = P'\, V_\mu(x,y')\, P'^{-1}$$

$$V_5(x,-y') = -P'\, W_5(x,y')\, P'^{-1}$$

5D Lagrangian is <u>inv.</u> under these tr.

$$V_\mu = T_a V_{\mu a}, \qquad V_5 = T_a V_{5a}$$

For $SU(2)_L$ and $U(1)_{B-L}$ gauge fields, we choose, $P = P' = I = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$

For $SU(2)_R$ gauge fields, we choose $P = I$, $P' = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$

$$V_R = \frac{1}{\sqrt{2}} \begin{pmatrix} W_{3R} & \sqrt{2} W_R^+ \\ \sqrt{2} W_R^- & -W_{3R} \end{pmatrix}$$

Then, under $Z_2 \times Z_2'$:

$$W_{R3} : (+,+), \quad W_R^\pm : (+,-)$$

$$W_5^3 : (-,-), \quad W_5^\pm : (-,+)$$

So, the fields can be Fourier expanded as

$$W_{R3}(x,y) = \sqrt{\frac{2}{\pi R}}\left[W_{R3}^{(0)}(x) + \sqrt{2}\sum_{n=1}^{\infty} W_{R3}^{(n)} \cos\frac{2ny}{R}\right], \text{ mass} = \frac{2n}{R}$$

$$W_R^{\pm}(x,y) = \frac{2}{\sqrt{\pi R}}\left[\sum_{n=0}^{\infty} W_R^{\pm(n)}(x) \cos\frac{(2n+1)y}{R}\right]; \text{ mass} = \frac{(2n+1)}{R}$$

$$W_5^{\pm}(x,y) = \frac{2}{\sqrt{\pi R}}\left[\sum_{n=0}^{\infty} W_5^{\pm(n)}(x) \sin\frac{(2n+1)y}{R}\right]; \text{ mass} = \frac{(2n+1)}{R}$$

$$W_5^{3}(x,y) = \frac{2}{\sqrt{\pi R}}\left[\sum_{n=0}^{\infty} W_5^{3(n)}(x) \sin\frac{(2n+2)y}{R}\right]; \text{ mass} = \frac{(2n+2)}{R}$$

$\Rightarrow$ only W_{R3} has massless mode

$\Rightarrow SU(2)_R$ is <u>broken</u> to $U(1)_R$.

Now, we use Higgs fields to break

$$SU(2)_L \times U(1)_R \times U(1)_{B-L} \to SU(2)_L \times U(1)_Y \to U(1)_{EM}$$

need: $\chi_R(1,2,\frac{1}{2})$, $\Phi_1(2,2,0)$

under $Z_2 \times Z_2'$:

$$\chi_R(x,-y) = P\chi_R(x,y)$$

$$\chi_R(x,-y') = -P'\chi_R(x,y)$$

$$\phi_1(x,-y) = \phi_1(x,y)P^{-1}$$

$$\phi_1(x,-y') = \phi_1(x,y)P'^{-1}$$

In order to break sym., χ_R and $\phi(2,2)$ must have VEVS $\Rightarrow$ must have zero modes.

$$\chi_R = \begin{pmatrix} \chi_R^+ \\ \chi_R^0 \end{pmatrix}, \quad \phi = \begin{pmatrix} \phi_{11}^0 & \phi_{12}^+ \\ \phi_{21}^- & \phi_{22}^0 \end{pmatrix}$$

Choose $P = \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}$, $P' = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$

Then, under $Z_2 \times Z_2'$:

$\chi_R^+ : (+,-)$, $\chi_R^0 : (+,+) \leftarrow$ massless mode

$\Rightarrow$ So χ_R^0 <u>can</u> have VEV

ϕ: $\begin{pmatrix} \phi_{11}^0 \\ \phi_{21}^- \end{pmatrix} : (+,+)$, $\begin{pmatrix} \phi_{12}^+ \\ \phi_{22}^0 \end{pmatrix} : (+,-)$

massless mode, can have VEV

<u>no</u> massless mode, <u>can't</u> have VEV.

So: $\langle \chi_R \rangle = \begin{pmatrix} 0 \\ v \end{pmatrix}$, $\langle \phi \rangle = \begin{pmatrix} k & 0 \\ 0 & 0 \end{pmatrix}$

In the usual L-R model:

$$\langle \Phi(2,2,0) \rangle = \begin{pmatrix} k & 0 \\ 0 & k' \end{pmatrix}$$

L-R mixing $\sim kk'$

So, in orbifold compactification model

$\Rightarrow$ <u>NO</u> L-R mixing

GAUGE BOSN- FERMION COUPLINGS

Fermion multiplets are same as in the usual L-R model:

$$\binom{u}{d}_L = \left(\tfrac{1}{2}, 0, \tfrac{1}{3}\right), \quad \binom{u}{d}_R = \left(0, \tfrac{1}{2}, \tfrac{1}{3}\right)$$

$$\binom{\nu_e}{e}_L = \left(\tfrac{1}{2}, 0, -1\right), \quad \binom{\nu_e}{e}_R = \left(0, \tfrac{1}{2}, -1\right)$$

We assume fermions are confined to the 4D wall at one of the fixed point, $y=0$.

: Write down the gauge interaction in 5D, supplemented by $\delta(y)$, and integrate over y

$$\Rightarrow \mathcal{L}_4^{(\text{neutral})} = \frac{g}{\cos\theta_W} Z_{i\mu}^{(n)} \left[A_i^{(n)} J^\mu_{V-A} + B_i^{(n)} J^\mu_{V+A} \right]$$

where $\quad J^\mu_{V\mp A} = \bar{\psi} \gamma^\mu \tfrac{1}{2}(1 \mp \gamma_5) \psi$

$Z_1^{(n)}, Z_2^{(n)} \Rightarrow$ KK excitations of $Z_1^{(0)}, Z_2^{(0)}$

$Z_3^{(n)} \Rightarrow$ KK excitation of the photon.

PHENOMENOLOGICAL IMPLICATIONS

Qualitative differences with the usual L-R Model

1 : KK excitations of both left and right handed gauge bosons

: Lowest W_R state is a KK excitation with mass $= \frac{1}{R}$

: Lowest KK excitation of W_L has mass $= \frac{2}{R}$

We shall see that current data restrict $\frac{1}{R}$ can be as low as $\sim 2\,\text{TeV}$.

$\Rightarrow$ At LHC, we may observe not only lightest W_R, but one or two KK excitations.

$\Rightarrow$ Show evidence of higher dimensions.

2 Unlike usual L-R model, no left-right mixing in the charged sector.

$\Rightarrow$: $W_R \not\rightarrow W_L \gamma$

: no assymmetry in polarized muon decay.

3 $W_R^{(0)}$ is a KK state

$\Rightarrow$ its coupling to fermion is larger by a factor $\sqrt{2}$ than in usual L-R model.

$\sigma_{W_2^{(0)}} = 2$ (usual L-R model)

$\Gamma_{W_2^{(0)}} = 2$ (" ").

But <u>not</u> for $Z_2^{(0)}$.

$\Rightarrow$ can easily distinguish from usual L-R model.

4 For our model,

$$R \equiv \frac{M^2_{W_2^{(0)}} \cos^2\theta_W}{M^2_{Z_2^{(0)}} \cos 2\theta_W} = 1 + \frac{1/R^2}{\frac{1}{2} g^2 v^2} > 1$$

whereas for usual L-R model, $R = 1$
(for the same Higgs multiplets)

Also, since $1/R > g v/\sqrt{2}$

: $W_2^{(0)}$ is expected to be heavier than $Z_2^{(0)}$

whereas in usual L-R model, W_R is higher than Z_R.

5 Less contribution to neutrinoless double beta decay (no L-R mixing).

LIMITS ON $Z_2^{(0)}$, $W_2^{(0)}$ MASSES AND ON $1/R$ FROM CURRENT DATA

$Z_2^{(0)}$ - Mass : Use precision LEP data:

We used F-B assymmetry in $e^+e^- \to Z_{pole} \to e^+e^-$

$$\rho \equiv \frac{M_{W_1}^2}{M_{Z_1}^2 \cos^2\theta_W}$$

For our model, $\rho = 1 + \Delta\rho_{LR} + \Delta\rho_{SM}$

$\Delta\rho_{LR} \simeq \cos 2\theta_W \dfrac{M_{Z_1}^2}{M_{Z_2}^2}$, $\Delta\rho_{SM} \simeq 3G_F m_t^2/8\sqrt{2}\pi^2$

Also, $\rho \equiv \dfrac{M_{W_1}^2}{\cos^2\theta_W M_{Z_1}^2} = \dfrac{M_{W_1}^2}{M_{Z_1}^2} \dfrac{4}{3 + \frac{g_V}{g_A}(1+\Delta\phi)}$

where $\Delta\phi \simeq -(1+\cos 2\theta_W) \dfrac{M_{Z_1}^2}{M_{Z_2}^2}$

Use $A_e = \dfrac{2 g_V g_A}{g_V^2 + g_A^2} = 0.15138 \pm 0.00216$

from F-B assymmetry

$\Rightarrow M_{Z_2^{(0)}} > 935\,\text{GeV}$ at 95% CL

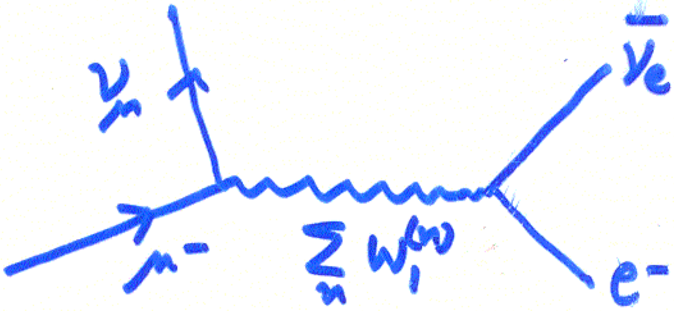
and $\dfrac{gV}{\sqrt{2}} > 780$ GeV at 95% CL

CONSTRAINTS ON $W_2^{(0)}$ MASS AND $1/R$:

: TWO WAYS ① muon decay
② $K^0 - \bar{K}^0$ mixing

① muon decay :

For our model, we get:

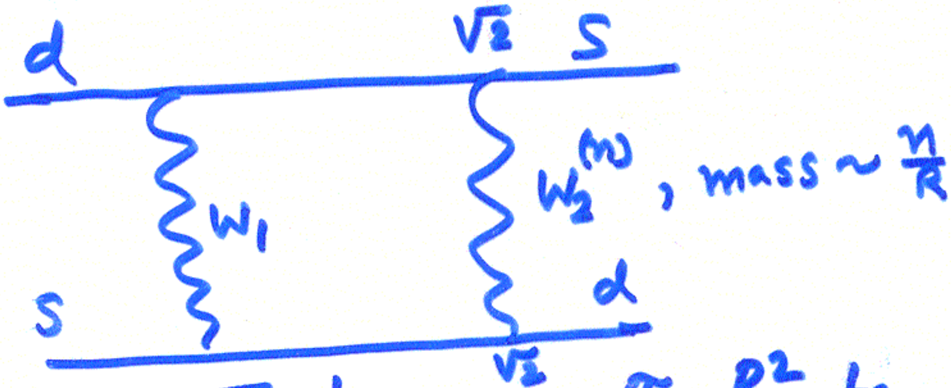


$$1 + 0.082\,\Delta\phi + \frac{\pi^2}{12} M_{W_1}^2 R^2$$
$$= 0.99928 \pm 0.0015$$

$$\Rightarrow \frac{1}{R} > 1.2 \text{ TeV at } 95\% \text{ CL}$$

② $K^0 - \bar{K}^0$ mixing :

: receives additional contributions



$$\frac{1}{\langle M_{W_2}^2 \rangle} = 2 \sum \frac{1}{M_{W_2^{(n)}}^2} = \frac{\pi}{2} \frac{R^2}{d} \tan\left(\frac{\pi}{2} d\right)$$

where $d = R\sqrt{\frac{g^2}{2}(v^2 + K^2)}$

$$\Rightarrow M_{W_2^{(0)}} > 2.5 \text{ TeV} \Rightarrow \frac{1}{R} > 1.9 \text{ TeV}$$

Also: in order to give mass to both up and down type quarks, need another $\phi\,(2,2,0)$ with $\langle\phi_1\rangle = \begin{pmatrix} \kappa_1 & 0 \\ 0 & 0 \end{pmatrix}$, $\langle\phi_2\rangle = \begin{pmatrix} 0 & 0 \\ 0 & \kappa_2 \end{pmatrix}$

GAUGE BOSON MASS MATRICES

Charged sector:

$$\left(W_L^{+(n)},\, W_R^{+(n)}\right) \begin{pmatrix} \boxed{\frac{g^2}{2}\kappa^2 + \left(\frac{2n}{R}\right)^2}, & 0 \\ 0, & \boxed{\frac{g^2}{2}(\kappa^2+v^2) + \left(\frac{2n+1}{R}\right)^2} \end{pmatrix} \begin{pmatrix} W_L^{-(n)} \\ W_R^{-(n)} \end{pmatrix}$$

where $\kappa^2 = \kappa_1^2 + \kappa_2^2$.

$\Rightarrow$ no left-right mixing

$\Rightarrow M^2_{W_1^{(n)}}$, $M^2_{W_2^{(n)}}$

Mass matrix for the neutral sector:

$$\frac{1}{2}\sum_{n=0}^{\infty}\left(W_{3L}^{(n)},\ W_{3R}^{(n)},\ B^{(n)}\right) M_{(n)}^2 \begin{pmatrix} W_{3L}^{(n)} \\ W_{3R}^{(n)} \\ B^{n} \end{pmatrix}$$

$$M_{(n)}^2 = \begin{pmatrix} \frac{g^2}{2}\kappa^2 + \left(\frac{2n}{R}\right)^2 & -\frac{g^2}{2}\kappa^2 & 0 \\ -\frac{g^2}{2}\kappa^2 & \frac{g^2}{2}(\kappa+v^2) + \left(\frac{2n}{R}\right)^2 & -\frac{gg'}{2}v^2 \\ 0 & -\frac{1}{2}gg'v^2 & \frac{g'^2}{2}v^2 + \left(\frac{2n}{R}\right)^2 \end{pmatrix}$$

$\Rightarrow$ no KK level mixing

$$\Rightarrow M_{A^{(0)}}^2 = 0$$

$$M_{Z_1^{(0)}}^2 \simeq \frac{M_{W_1^{(0)}}^2}{\cos^2\theta_W}\left\{1 - (1-\tan^2\theta_W)\frac{\kappa^2}{v^2}\right\}$$

$$M_{A^{(n)}}^2 \simeq M_{Z_1^{(n)}}^2 \simeq \left(\frac{2n}{R}\right)^2, \quad n \geq 1$$

$$M_{Z_2^{(n)}}^2 \simeq \left(\frac{2n}{R}\right)^2 + \frac{\cos^2\theta_W}{2\cos 2\theta_W} g^2 v^2, \quad n \geq 0$$

θ_W = weak mixing angle,

$$\tan\theta_W = \frac{g_Y}{g}, \quad g_Y = \frac{gg'}{\sqrt{g^2+g'^2}}$$

CONCLUSIONS

: GAUGE SYM. BREAKING USING ORBIFOLD COMPACTIFICATION IS AN INTERESTING ALTERNATIVE TO HIGGS MECHANISM

: APPLIED TO L-R GAUGE SYM IN 5D

: $SU(2)_R$ (AS WELL AS PARITY) IS BROKEN TO $U(1)_R$ UPON COMPACTIFICATION

: SEVERAL DISTINGUISHING FEATURES FROM THE USUAL L-R MODEL IN 4D

⇒ EXISTENCE OF KK EXCITATIONS

⇒ NO L-R MIXING

⇒ LIGHTEST W_R IS A KK STATE, $Z_R^{(0)}$ IS NOT

⇒ BOUNDS ON $W_2^{(0)}$, $Z_2^{(0)}$ LOW ENOUGH SO THAT LHC CAN PRODUCE THOSE, AS WELL AS 1 OR 2 KK EXCITATIONS ⇒ EXISTENCE OF EXTRA DIM

⇒ PRODUCTION CROSS SECTIONS AS WELL AS DECAY WIDTH LARGE BY 2 FOR $W_2^{(0)}$, BUT NOT FOR $Z_2^{(0)}$.