Gauge-Higgs Unification at LHC

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Gauge-Higgs Unification

Origin of symmetry breaking

Origin of the Higgs

Principle for the Higgs

4D Higgs is unified with gauge fields in higher dimensions

$$A_M = (A_\mu , A_{y_j})$$

gauge principle + background spacetime

Naturally light Higgs.

Higgs interactions predicted.

余剰次元での AB位相　＝　ヒッグス場

非可換ゲージ理論では AB位相は荷電場

ゲージ対称性の破れを引き起こす

$$e^{ig\Theta_H} \sim \exp\left\{ig\int A_y dy\right\}$$

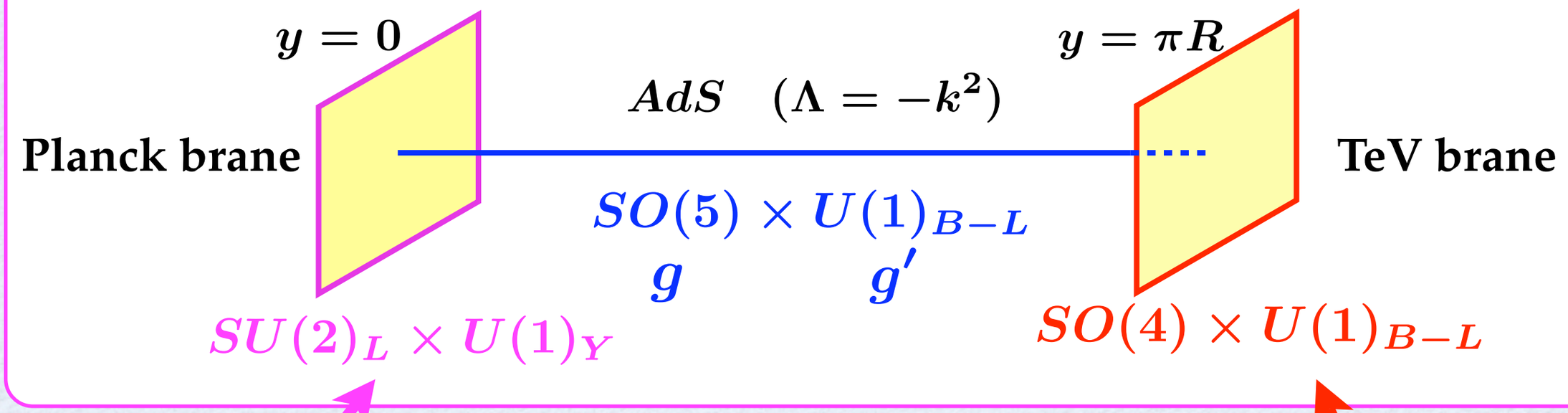
量子効果により　$e^{ig\Theta_H}$　が決まり

質量が生成される。

何がよいか：　ゲージ原理ですべてが決まる

SO(5)xU(1) model in the RS warped space

$$ds^2 = e^{-2k|y|} dx_\mu dx^\mu + dy^2$$



$$P_0 = \begin{pmatrix} -1 & & & & \\ & -1 & & & \\ & & -1 & & \\ & & & -1 & \\ & & & & +1 \end{pmatrix}$$

+ brane dynamics

Hosotani mechanism

$$\theta_H \neq 0$$

$$P_1 = \begin{pmatrix} -1 & & & & \\ & -1 & & & \\ & & -1 & & \\ & & & -1 & \\ & & & & +1 \end{pmatrix}$$

$U(1)_{EM}$

$SO(5) \times U(1)$ model

Agashe, Contino, Pomarol 2005
Hosotani, Sakamura 2006
Medina, Shah, Wagner 2007

Higgs

$$P_0 = P_1 = \begin{pmatrix} -1 & & & & \\ & -1 & & & \\ & & -1 & & \\ & & & -1 & \\ & & & & +1 \end{pmatrix} \Rightarrow A_y \sim \begin{pmatrix} & & & \phi_1 \\ & & & \phi_2 \\ & & & \phi_3 \\ & & & \phi_4 \\ & & & \end{pmatrix} \quad \Phi = \begin{bmatrix} \phi_1 + i\phi_2 \\ \phi_4 - i\phi_3 \end{bmatrix}$$

$$SO(5) \to SO(4) \simeq SU(2)_L \times SU(2)_R$$

Fermions

$$\begin{pmatrix} T_L & T_R \\ B_L & B_R \\ t_L & t_R \\ b_L & b_R \\ t'_L & t'_R \end{pmatrix} \quad \begin{pmatrix} U_L & U_R \\ D_L & D_R \\ X_L & X_R \\ Y_L & Y_R \\ b'_L & b'_R \end{pmatrix}$$

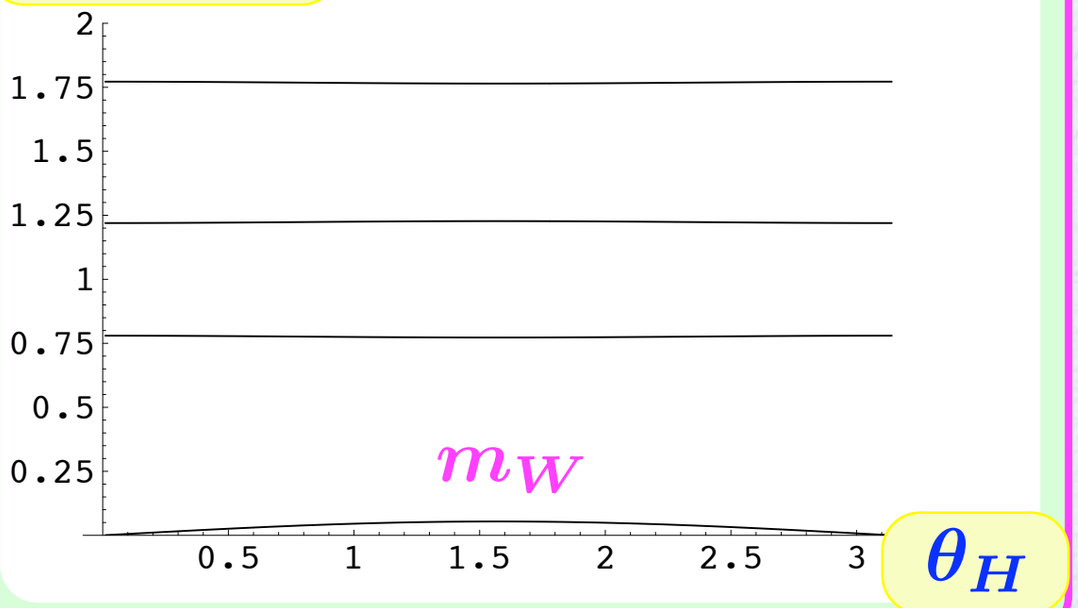
3rd generation ($c_{\rm bulk} \sim 0.43$)

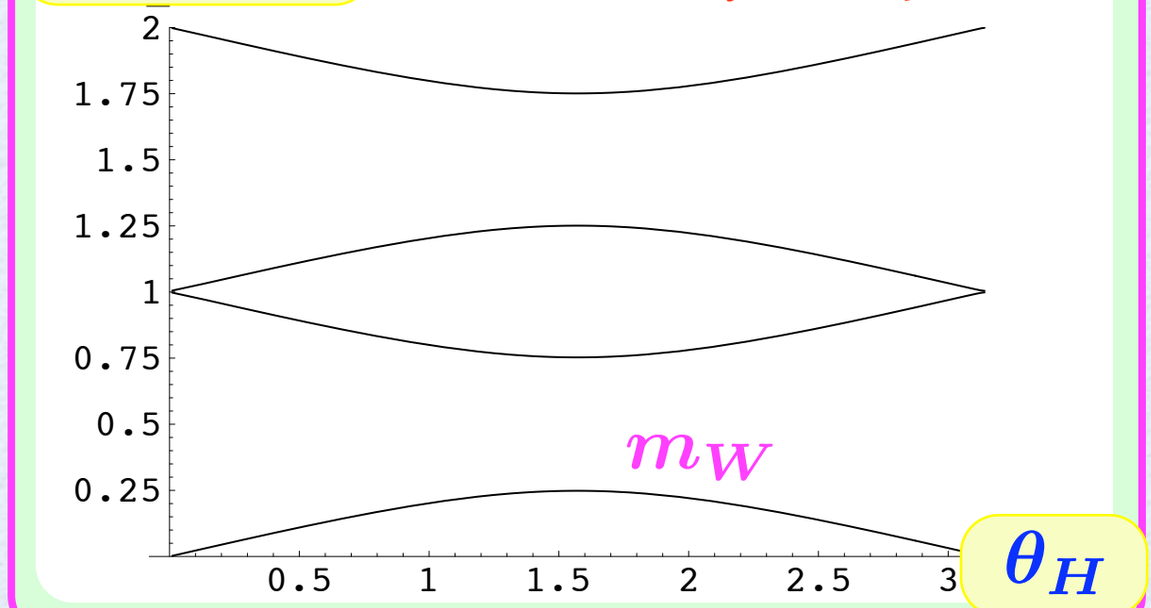
⇒ *EW sym. breaking*

in preparation

(Y.H., Oda, Sakamura, Medini, Ohnuma)

KK tower of W-boson





$m_W \ll M_{KK}$

$m_W \sim (0.1 \sim 0.2)\, m_{KK}$

KK mass scale

$$M_{KK} \sim \frac{\pi k}{e^{\pi k R} - 1} = \begin{cases} 1/R & \text{in flat space} \\ \pi k\, e^{\pi k R} & \text{in RS} \end{cases}$$

Wave functions

γ

$$\sin\theta_W (T_L^3 + T_R^3) + \sqrt{1 - 2\sin^2\theta_W}\; T_B$$

Flat

W

$$h_L^+(y)\, T_L^+ + h_R^+(y)\, T_R^+ + \hat{h}^+(y)\, \hat{T}^+$$

$SU(2)_L$ $SU(2)_R$ $SO(5)/SO(4)$

$$h_L^+ \sim 1 + \cos\theta_H$$

$$h_R^+ \sim 1 - \cos\theta_H$$

$$\hat{h}^+ \sim \sqrt{2}\sin\theta_H \left(1 - \frac{e^{2ky}}{e^{2k\pi R}}\right)$$

Almost flat in RS !

Higgs

$$h_H \sim e^{2ky}$$

Localized at TeV brane

4D gauge and Higgs couplings

$$F_{MN}{}^2 \sim (\partial_\mu A_\nu - \partial_\nu A_\mu + g[A_\mu, A_\nu])^2$$

WWZ
WWZZ
WWWW

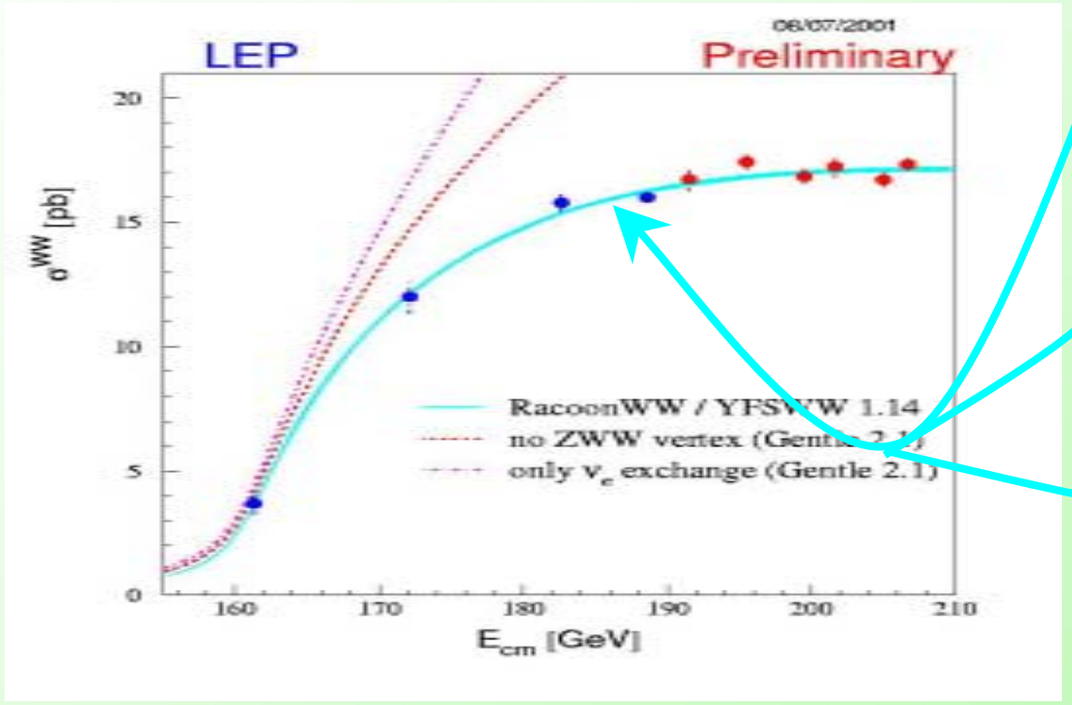
$$+(\partial_\mu A_y - \partial_y A_\mu + g[A_\mu, A_y])^2$$

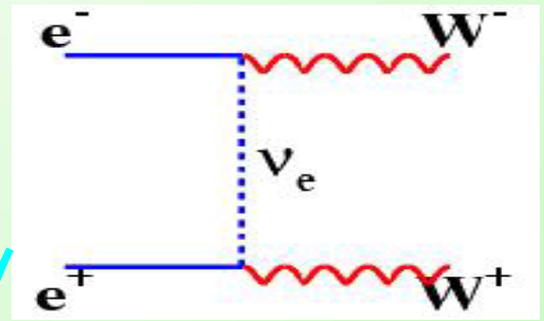
WWH
ZZH
WWHH
ZZHH

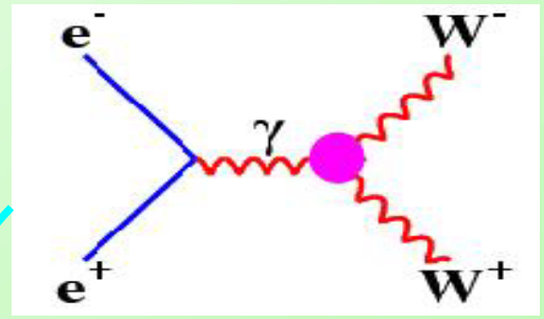
WWZ coupling

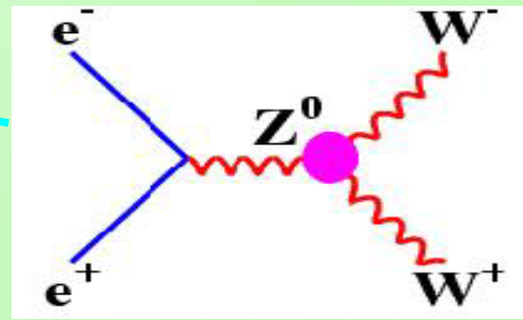
Triple gauge boson vertex

The $e^+e^- \rightarrow W^+W^-$ cross section measurement at LEP2 is in perfect agreement with the Standard Model triple gauge boson vertex WWγ e WWZ





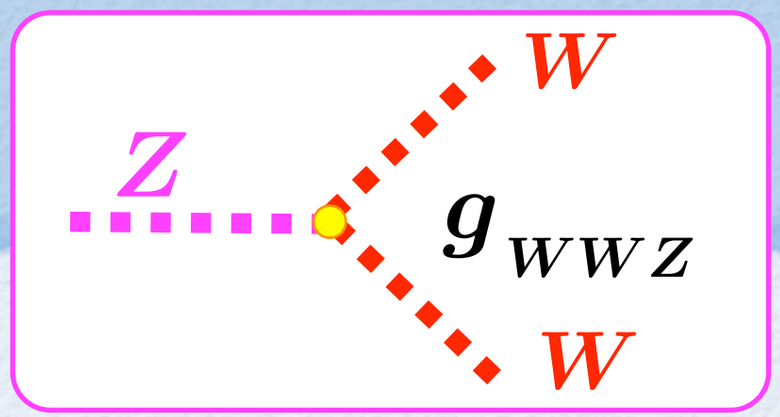




19/02/2002 Riccardo Paramatti 16

from R. Paramatti, 2002

WWZ coupling



$$g_{WWZ} = g_A \int dy \left[h_Z^{3_L} \left\{ \left(h_W^{+_L}\right)^2 + \tfrac{1}{2}\left(h_W^{\hat{+}}\right)^2 \right\} \right.$$
$$\left. + h_Z^{3_R} \left\{ \left(h_W^{+_R}\right)^2 + \tfrac{1}{2}\left(h_W^{\hat{+}}\right)^2 \right\} + h_Z^{\hat{3}} h_W^{\hat{+}} \left(h_W^{+_L} + h_W^{+_R} \right) \right]$$

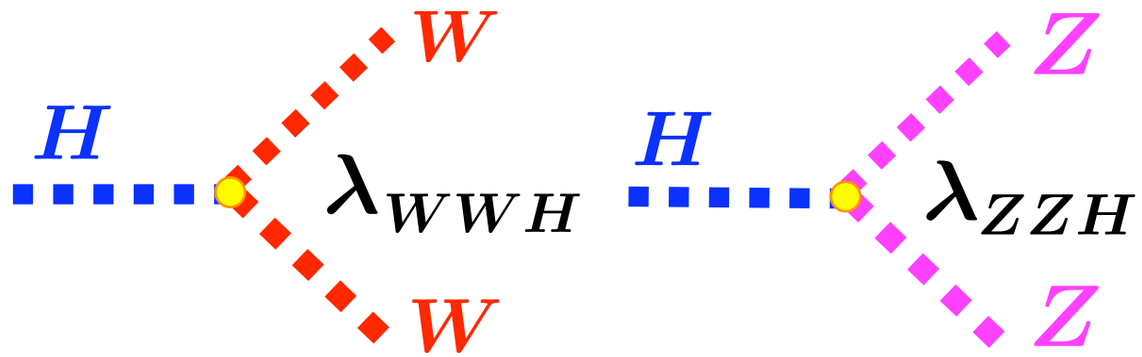
$$g_{WWZ} \simeq g \cos\theta_W$$

θ_H	$\pi/10$	$\pi/4$	$\pi/2$
$k\pi R$ =35	0.9999987	0.999964	0.99985
0.35	0.9994990	0.979458	0.83378

Almost universal in RS

Deviation in flat space

Higgs WWH & ZZH coupling



$$\mathcal{L}_{\rm int}^{4D} \sim -\frac{1}{2} g_4^2 f_H^2 \sin^2\left(\theta_H + \frac{H}{\sqrt{2} f_H}\right) \left\{ W_\mu^\dagger W^\mu + \frac{1}{2\cos^2\theta_W} Z_\mu Z^\mu \right\}$$

$$m_W = \frac{1}{\sqrt{2}} g_4 f_H \sin\theta_H \qquad m_Z = \frac{m_W}{\cos\theta_W}$$

WWH	$g_4 m_W \cos\theta_H$	ZZH	$\frac{g_4 m_Z}{\cos\theta_W} \cos\theta_H$
$WWHH$	$g_4^2 \cos 2\theta_H$	$ZZHH$	$\frac{g_4^2}{\cos^2\theta_W} \cos 2\theta_H$

suppression

EW Gauge-Higgs Unification in the Warped Space

	RS	**flat**
m_H	$\mathbf{140 \sim 280\ GeV}$	$\mathbf{\sim 10\ GeV}$
m_{KK}	$\mathbf{1.5 \sim 3.5\,TeV}$	$\mathbf{\sim 800\ GeV}$
WWZ $WWZZ$ $WWWW$	**almost universal**	**deviation**
$Wq\bar{q}'$ $W\ell\bar{\nu}$	**tiny universality violation**	
WWH ZZH	**suppressed by $\cos\theta_H$ may vanish ($\theta_H = \pi/2$)**	
Yukawa/m_F	**suppressed by $\cdots$**	
m_F	**natural hierarchy**	**fine tuning**

Gauge-Higgs Unification at LHC

Higgs mass

Higgs interactions

WWH , ZZH

Yukawa $t\bar{t}H$

Origin of EW symmetry breaking