Higgs mass and anomalous Higgs interactions in gauge-Higgs unification

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@ Planck 2014 (May 28, '14, Paris)

I. Introduction

The origin of the Higgs is unclear.

A hint: the Higgs is light !

⇒ Higgs self-coupling is governed by gauge principle

Namely, among physics BSM the following scenarios seem to be favored:

- MSSM “ D-term“ contribution

$$V = \frac{1}{2} g^2 [\phi_u^\dagger \tau^a \phi_u + \phi_d^\dagger \tau^a \phi_d]^2 + \cdots$$

In this talk we focus on

- Gauge-Higgs Unification (GHU)

("holographic composite Higgs")

The **origin of Higgs: gauge boson**

(N.S. Manton ('79), Y. Hosotani ('83)):

$$A_M = (A_\mu, A_y) \quad (D=5)$$

$$A_y^{(0)}(x) = H(x): \ \text{Higgs}$$

GHU provides a solution to the hierarchy problem without relying on SUSY, as the Higgs mass is protected under the quantum correction by (higher dimensional) gauge symmetry.

(H. Hatanaka, T. Inami and C.S. Lim., Mod. Phys. Lett. A13('98)2601)

(N.B.) Both MSSM and GHU were devised in order to solve the hierarchy problem invoking some symmetry.

II. Anomalous Higgs interaction

As these scenarios have been proposed in order to solve the hierarchy problem concerning Higgs, they expand or give new interpretation of the Higgs sector.

$\Rightarrow$ It is quite natural to expect that the Higgs interactions deviate from what SM predict:

"anomalous Higgs interaction"

$\Rightarrow$ We hope the precision tests at ILC etc. will tell us which scenario is actually realized in nature.

(Normal vs. anomalous Higgs interactions)

Normal (as in SM) Higgs interactions:

- UED

Anomalous Higgs interactions:

- SUSY (MSSM)

$$\frac{f_t^{(MSSM)}}{f_t^{(SM)}} = \frac{\cos\alpha}{\sin\beta}, \quad \frac{f_b^{(MSSM)}}{f_b^{(SM)}} = \frac{f_\tau^{(MSSM)}}{f_\tau^{(SM)}} = -\frac{\sin\alpha}{\cos\beta}.$$

- GHU, Dimensional deconstruction, Little Higgs

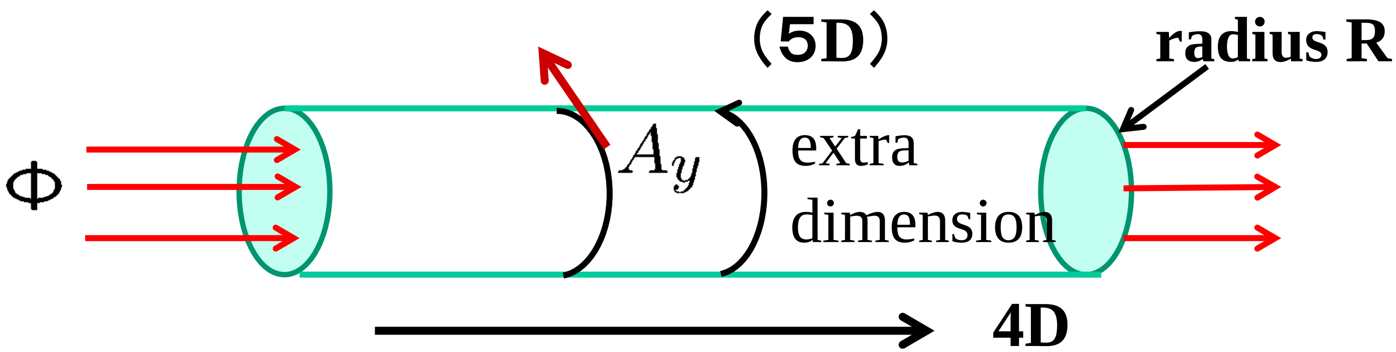
Anomalous Higgs interaction in GHU

(K. Hasegawa, N. Kurahashi, C.S. Lim, K. Tanabe, P.R.D87('13)016011)

In GHU, $H(\leftarrow A_y^{(0)})$ has a physical meaning as Wilson loop (AB phase):

$$W = e^{i\frac{g}{2}\oint A_y dy} = e^{ig_4 \pi R A_y^{(0)}} = e^{i\frac{g_4}{2}\Phi} \quad \text{(Abelian)}$$

(Circle : non-simply-connected)



We expect in GHU physical observables have periodicity in H

$$v \quad \rightarrow \quad v + \frac{2}{g_4 R} \quad (g_4 : \text{4D gauge coupling})$$

In fact, we find for the (zero-mode) quarks of lighter generations,

$$m(v) \propto \sin(\frac{g_4}{2}\pi R v)$$: non-linear in v !

⇩

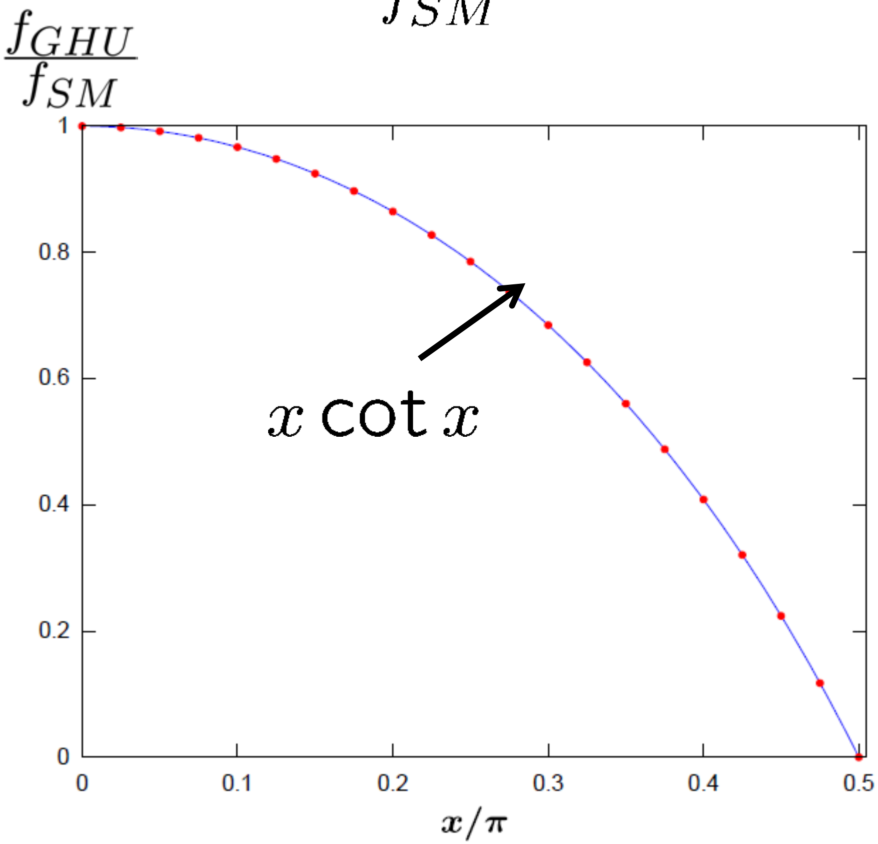
$$f = \frac{dm(v)}{dv} \propto \cos(\frac{g_4}{2}\pi R v)$$

: even vanishes for $x \equiv \frac{g_4}{2}\pi R v = \frac{\pi}{2}$!

(Y. Hosotani, K. Oda, T.Ohnuma, Y. Sakamura, P.R.D78('08)096002)

The anomalous Yukawa coupling of the zero-mode:

$$\frac{f_{GHU}}{f_{SM}} \simeq x \cot x$$



(N.B.)

- In the "decoupling limit"

$$x = \frac{g_4}{2} v \pi R \ll 1 \leftrightarrow M_W \ll \frac{1}{R}$$

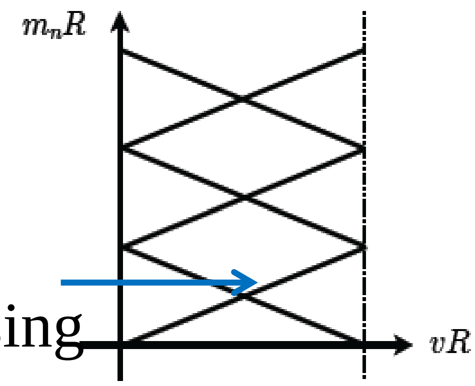
SM prediction is recovered

The anomalous interaction may be attributed not only to the periodicity but also to the

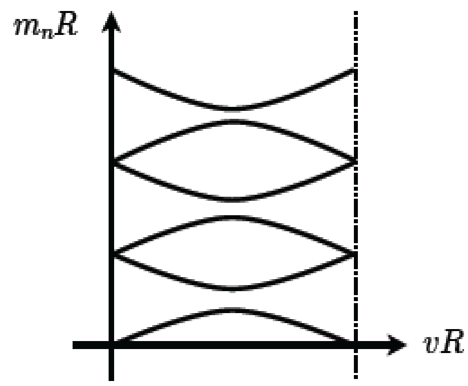
breakdown of translational invariance in extra space.

(Mass spectrum)

level crossing



(a)



(b)

Z_2-odd bulk mass:

$$\epsilon(y) M \bar{\psi}\psi$$

with

$$\epsilon(y) = \pm 1$$

(for $y > 0, \ < 0$)

M = 0,
translational invariance ○
no mixing between KK modes

M $\neq$ 0,
translational invariance ×
mixing appears

In the scenarios, which have close relations with GHU, similar anomalous Higgs interactions are expected.

- Dimensional deconstructiom: “latticized” GHU
  the translational invariance is broken by latticizing the extra dimension
  (N. Kurahashi, C.S. Lin, K. Tanabe, paper in preparation)

$$m_n(v) = \frac{2}{a}\sin\left(\frac{n\pi}{N} + \frac{g_4 a v}{4}\right) \quad (a : \text{lattice spacing})$$

, though the anomaly just goes away in the continuum limit

$$a \to 0 \quad (N \to \infty)$$
$$m(v) \to \frac{n}{R} + \frac{1}{2} g_4 v$$

- Little Higgs
  Higgs is nonlinearly realized: $U = e^{i\frac{H}{v}}$

III. The prediction of the Higgs mass in GHU

What does the value $M_H = 126\ (\mathrm{GeV})$ mean ?

Interestingly, again in the types of BSM with anomalous Higgs interactions, Higgs mass is calculable as a finite value and testable.

- In MSSM

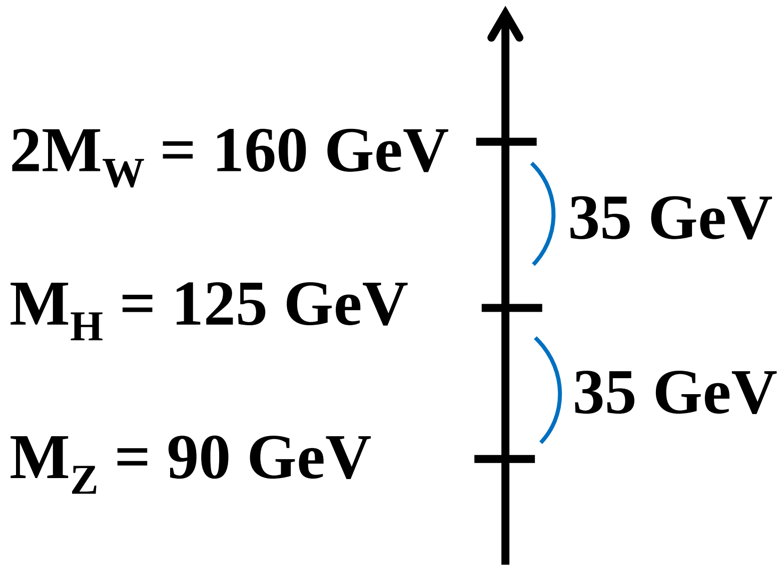
@classical level, Higgs mass is related to the gauge boson mass ← self-coupling comes from the D-term:

$$M_H \leq M_Z |\cos 2\beta|$$

@quantum level, "large" but calculable quantum correction can account for the observed Higgs mass:

$$M_{h^0}^2 \leq M_Z^2 + \frac{3m_t^4}{\pi^2 v^2} \ln\left(\frac{m_s}{m_t}\right)$$

(N.B.) Interestingly,



- **In GHU**

(C.S. Lim, N. Maru and T. Miura, rXiv:1402.6761[hep-ph])

In 6D GHU, Higgs has a self- interaction (for Z_3 - orbfold)
via $[A_5, A_6]^2$ in (1/4) $F^{MN}F_{MN}$

$\Rightarrow$ $M_H = 2M_W$ **(@ tree level)**

(Scrucca, Serone, Silverstrini, Wulzer, ’04)

Calculable Higgs mass in GHU

Now two observables have been completely determined:

$$M_H^2 = (126\text{GeV})^2$$
$$\Delta \equiv (\frac{M_H}{2M_W})^2 - 1 = -0.380$$

In GHU, these are both calculable as finite values.

Relevant terms $$-(-\mu^2|h_0|^2 + \lambda|h_0|^4) + \kappa|h_0|^2 W^{+\mu}W_\mu^-,$$

$$\to \quad M_H^2 = 2\mu^2, \quad \Delta = \frac{\lambda}{\kappa} - 1$$

@ tree level,

$$\mu_{tree}^2 = 0, \quad \lambda_{tree} = \kappa_{tree} = \frac{1}{2}g^2$$
$$\to \quad M_H^2 = 0, \quad \Delta = 0 \ (M_H = 2M_W).$$

, since the relevant operators are all due to a single local operator

$(1/4)\ F^{MN}F_{MN}$

@ quantum level

Still, both M_H^2, Δ are calculable as UV-finite values, since the quantum correction to the local operator

(1/4) $F^{MN}F_{MN}$

does not spoil the tree level relation, though its Wilson coefficient is UV-divergent:

$$M_H^2 = -\frac{\sqrt{3}}{16\pi}g^2\frac{1}{R^2}\sum_{(k,l)\neq(0,0)}\int_0^\infty du(2u+\hat{M}^2)e^{-\frac{\hat{M}^2}{u}}e^{-\pi^2(k^2+kl+l^2)u},$$

$$\Delta = -\frac{\sqrt{3}}{64\pi}g^2\sum_{(k,l)\neq(0,0)}\int_0^\infty du\left(1+\frac{\hat{M}^2}{u}+\frac{1}{3}\frac{\hat{M}^4}{u^2}\right)e^{-\frac{\hat{M}^2}{u}}e^{-\pi^2(k^2+kl+l^2)u},$$

, in a toy model of 6D scalar QED, where scalar matter has a bulk mass M and $\hat{M} \equiv RM$

For small $\widehat{M}$,

$$|M_H^2| \simeq 0.0685 \frac{\alpha}{\sin^2\theta_W} \frac{1}{R^2} = 2.2 \times 10^{-3} \frac{1}{R^2},$$

$$|\Delta| \simeq 3.25 \times 10^{-2} \frac{\alpha}{\sin^2\theta_W} (-\ln \widehat{M}^2) = 2.0 \times 10^{-3} (-\ln \widehat{M}),$$

$$\rightarrow \quad \frac{1}{R} \simeq 2.7 \ \text{TeV}, \quad -\ln \widehat{M} \simeq 190.$$