Higgs boson as a gauge field in extra dimensions

-- Pinning it down at LHC and ILC

Yutaka Hosotani

Physics
OSAKA UNIVERSITY

with Funatsu, Hatanaka, Orikasa, Shimotani

1301.1744 [PLB 722 (2013) 94]

Higgs and Beyond, Tohoku Univ, 7 June 2013

125 - 126 GeV Higgs boson was found.

Higgs decay: $H \to \gamma\gamma\ ,\ gg, ZZ, \cdots$

Branching fractions: consistent with SM

~~Signal for SM ?~~

Signal for Extra Dimensions !

from old slides in 2007

The Most Wanted Higgs Particle

Yutaka Hosotani, Osaka University

The 5th COE International Symposium, Tohoku University
14 - 16 February 2007

Conclusions from old slides in 2007

Find Higgs.

Determine the Higgs couplings

to establish

Identity of the Higgs

Mechanism of EW symmetry breaking.

We may find

Extra Dimensions

in the Gauge-Higgs Unification.

Gauge-Higgs unification

gauge theroy A_M *in 5 dim.*

4-dim. components A_μ

∪

4D gauge fields

γ , W , Z

extra-dim. component A_y

∪

4D Higgs fields

H

Aharonov-Bohm phase

θ_H

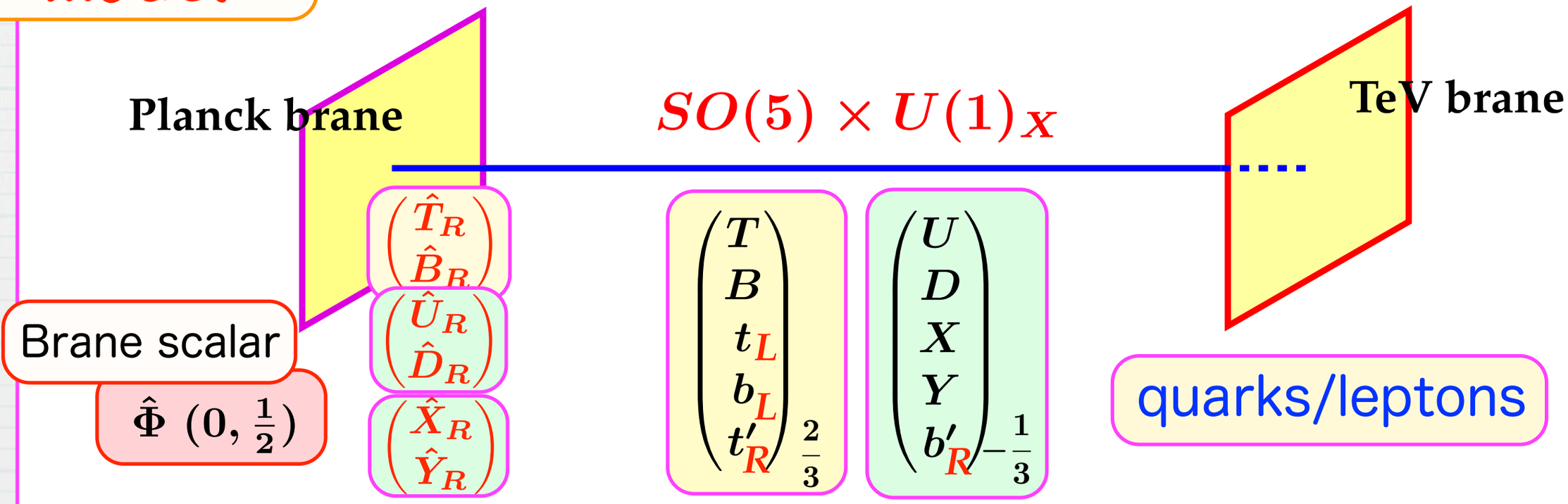
EW symmetry breaking

Hosotani mechanism

SO(5)xU(1) gauge-Higgs unification in RS

Previous model

Agashe, Contino, Pomarol, 2005
YH, Oda, Ohnuma, Sakamura 2008
YH, Noda, Uekusa 2009



SM content
anomaly cancellation

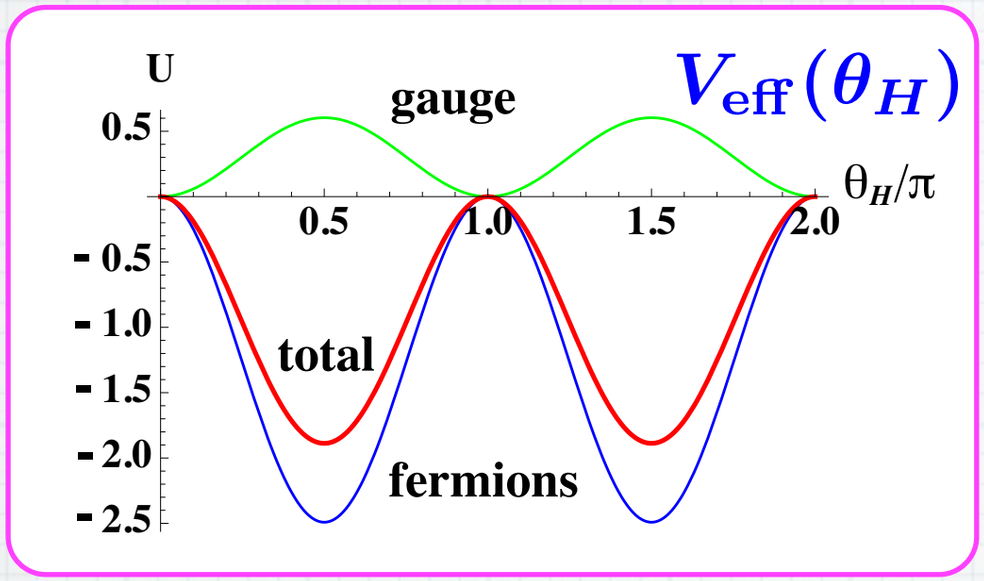
$SO(5) \times U(1)_X$

$\Rightarrow$ B.C. $SO(4) \times U(1)_X$

Hosotani mechanism

$\Rightarrow$ $SU(2)_L \times U(1)_Y$ $\Rightarrow$ $\theta_H \neq 0$ $U(1)_{EM}$

However



$$\theta_H = \frac{\pi}{2}$$

stable Higgs !?

☹

new Model

Funatsu, Hatanaka, YH, Orikasa, Shimotani, 1301.1744

Add n_F extra fermions Ψ_F in the spinor rep.

$$\Psi_F(x,-y) = P_0\gamma_5\Psi_F(x,y)$$
$$\Psi_F(x,L-y) = -P_1\gamma_5\Psi_F(x,L+y)$$

Physics turns out independent of n_F

$V_{\rm eff}(\theta_H)$ & m_H

parameters

$k,\ z_L = e^{kL},\ g_A,\ g_B$

$c_t,\ \tilde{\mu}/\mu_2$

$c_F,\ n_F$

input

$m_Z,\ g_w,\ \sin^2\theta_W$

$m_t,\ m_b$

m_H

$V_{\rm eff}$

$$\theta_H \ :\ \frac{dV_{\rm eff}}{d\theta_H} = 0$$

$$m_H^2 = \frac{1}{f_H^2}\frac{d^2V_{\rm eff}}{d\theta_H^2}\bigg|_{\rm min}$$

$m_H = 126\,{\rm GeV}$

$\theta_H(z_L, n_F)$

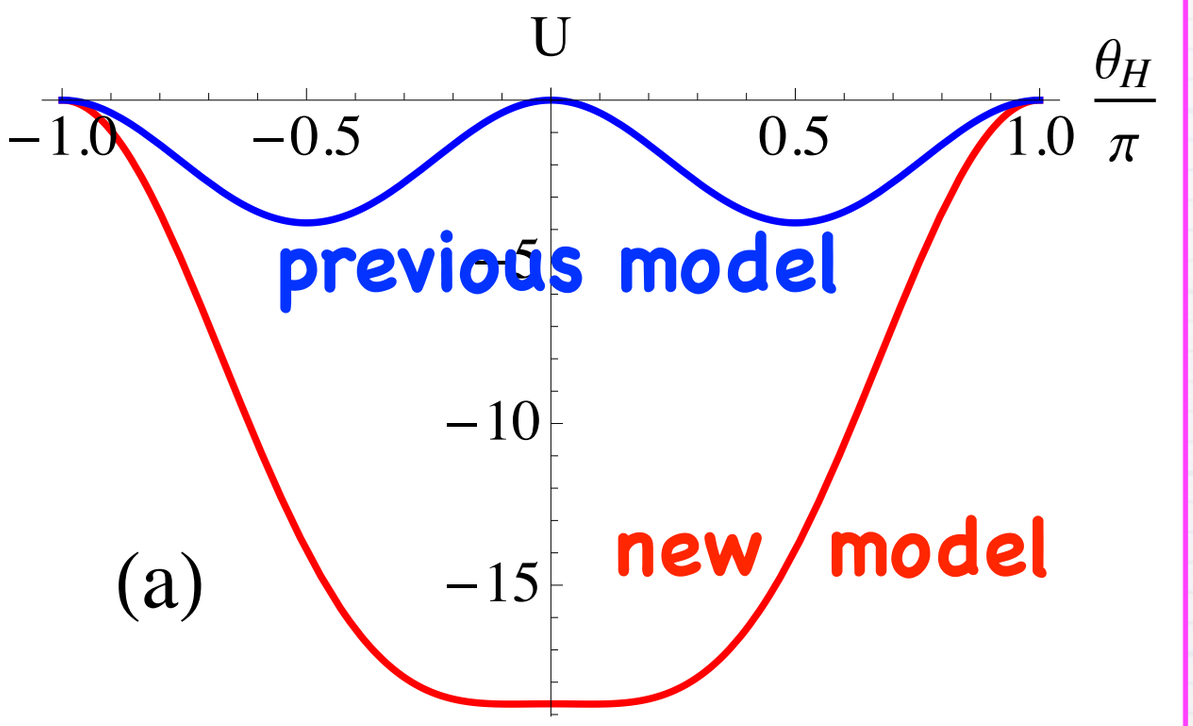
gauge couplings

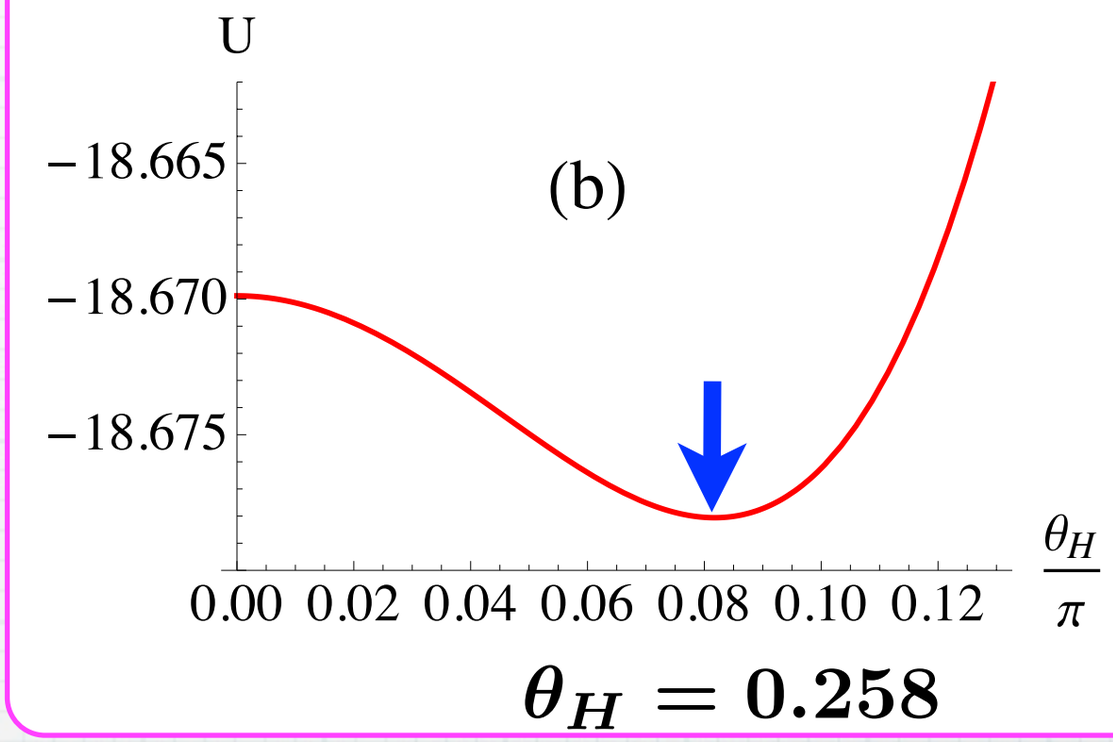
Higgs couplings

KK spectrum

$$V_{\rm eff} = \left(\frac{m_{\rm KK}}{2\pi} \right)^4 U$$

$$n_F = 3 \ , \ z_L = 10^7$$
$$c_t = 0.330 \ , \ c_F = 0.353$$





$$\theta_H = 0.258$$

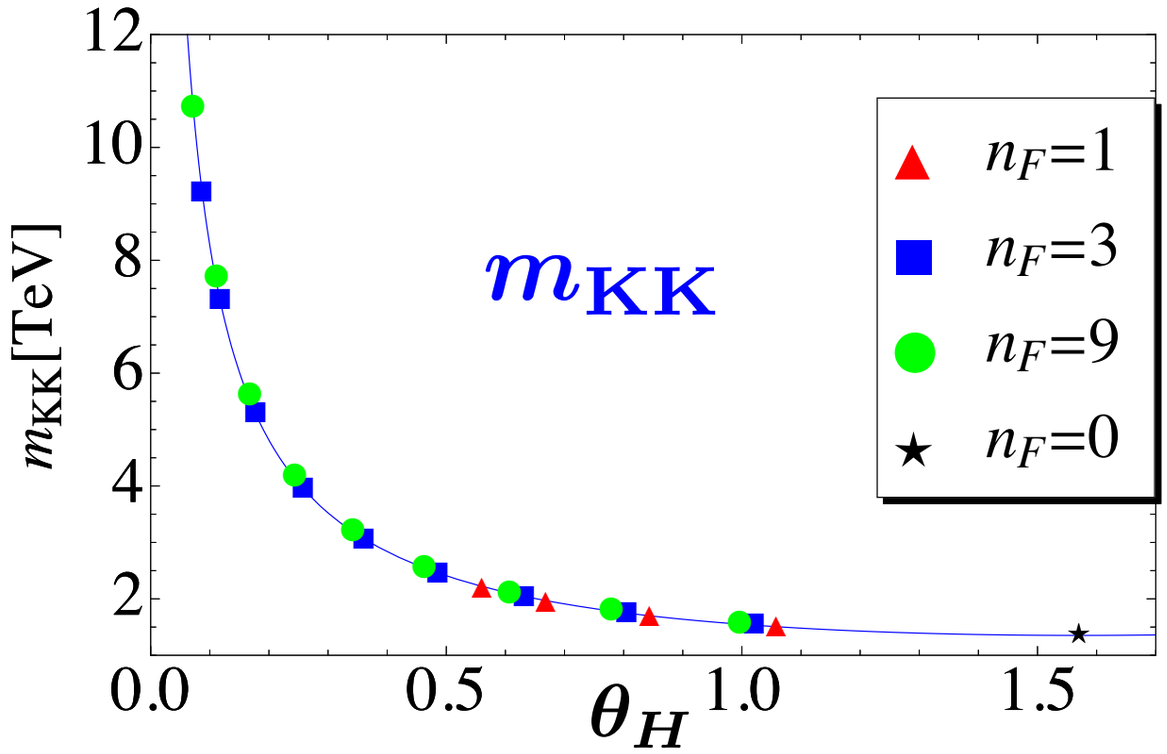
EW symmetry breaking takes place.

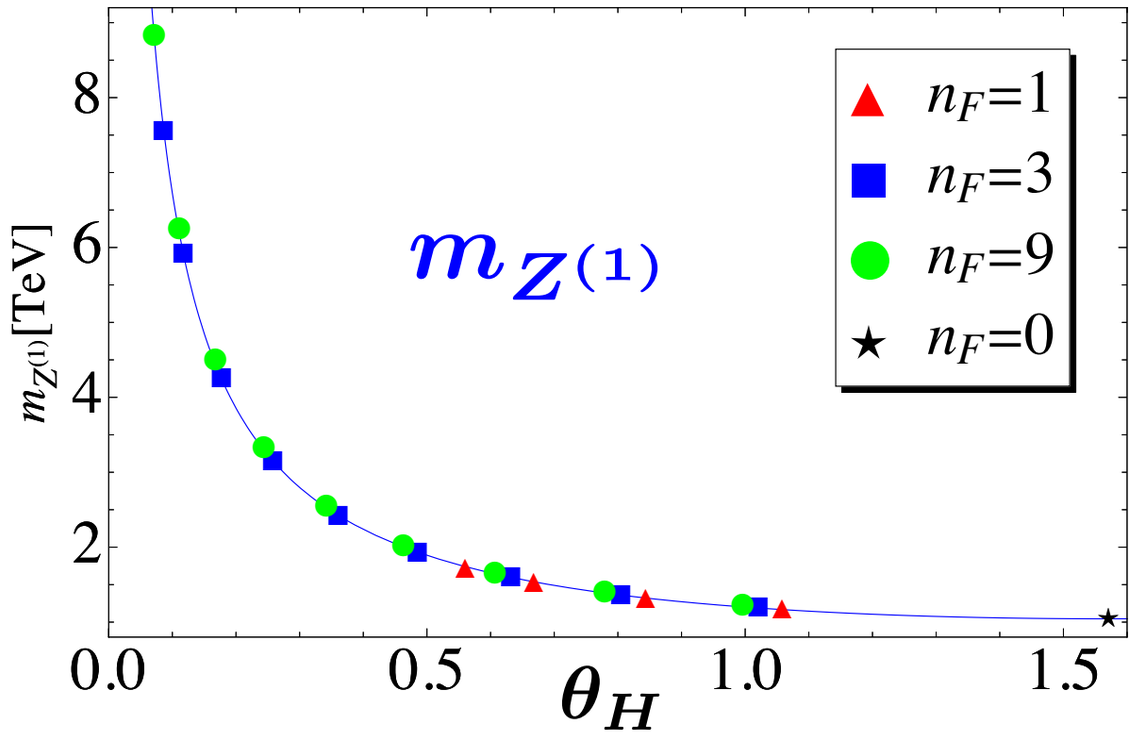
Higgs boson at 126 GeV.

(No instability problem in GH. ⇔ SM, UED)

$\theta_H(z_L, n_F)$ & $m_{\mathrm{KK}}(z_L, n_F)$ $m_{Z^{(1)}}(z_L, n_F)$

input $m_H = 126\,\mathrm{GeV}$



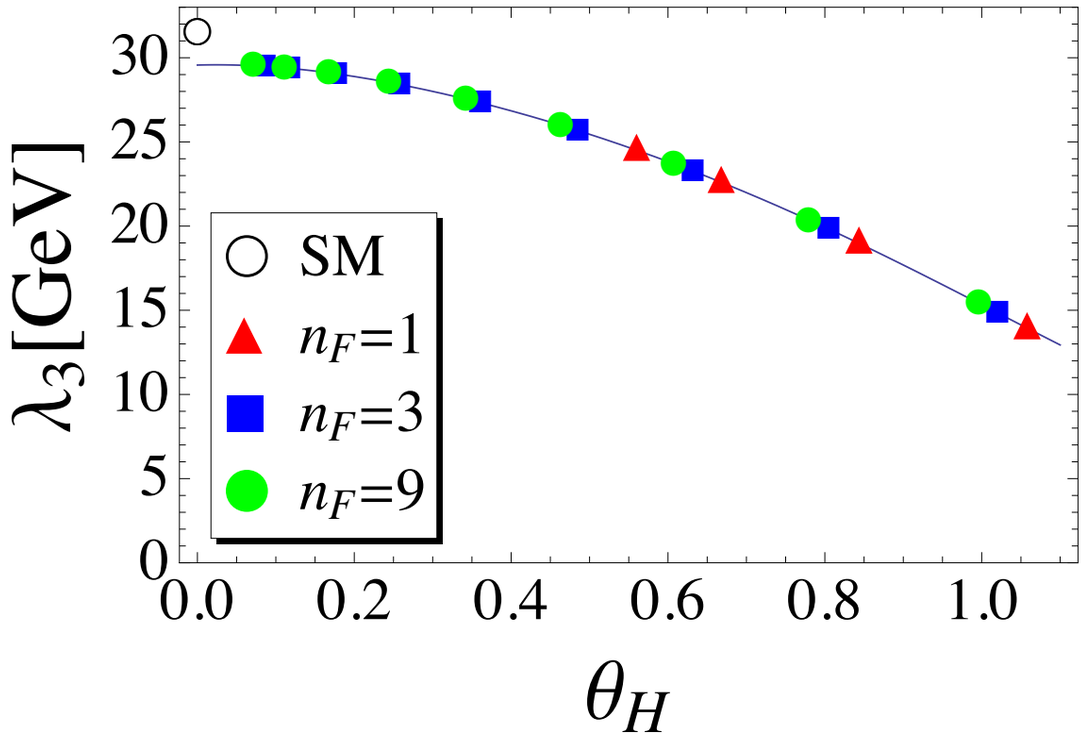


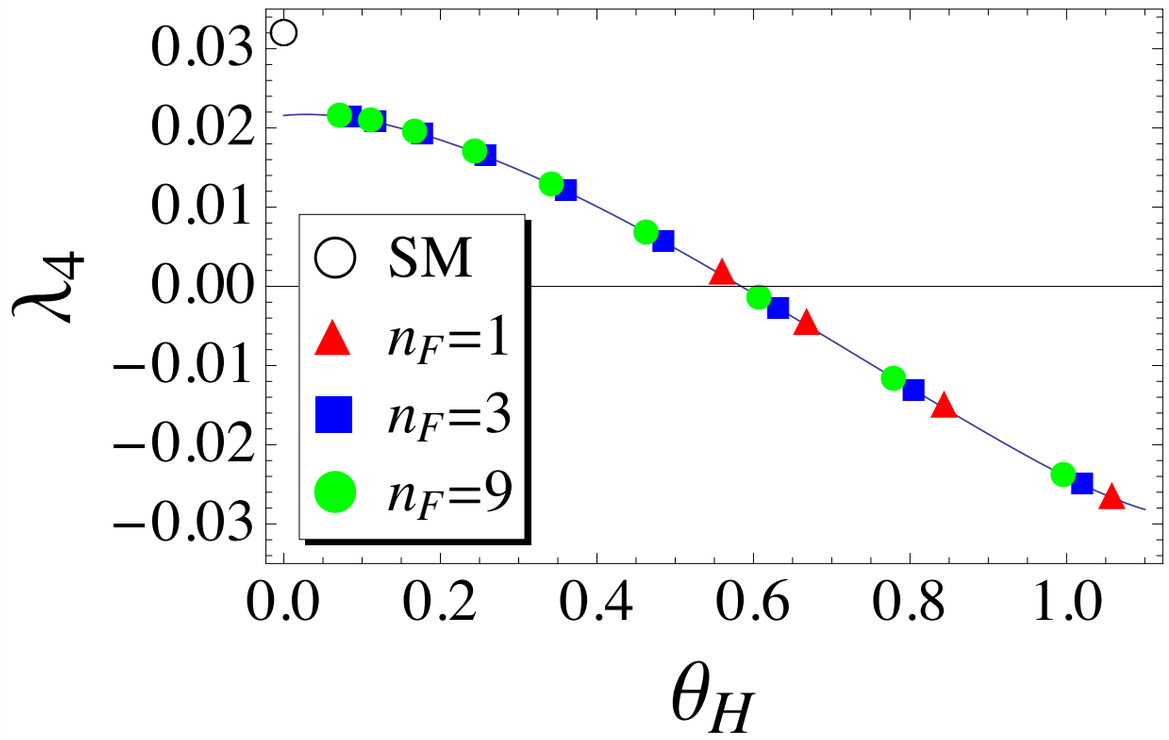
$$m_{\mathrm{KK}} \sim \frac{1352\,\mathrm{GeV}}{(\sin\theta_H)^{0.786}}$$

$$m_{Z^{(1)}} \sim \frac{1044\,\mathrm{GeV}}{(\sin\theta_H)^{0.808}}$$

Universality

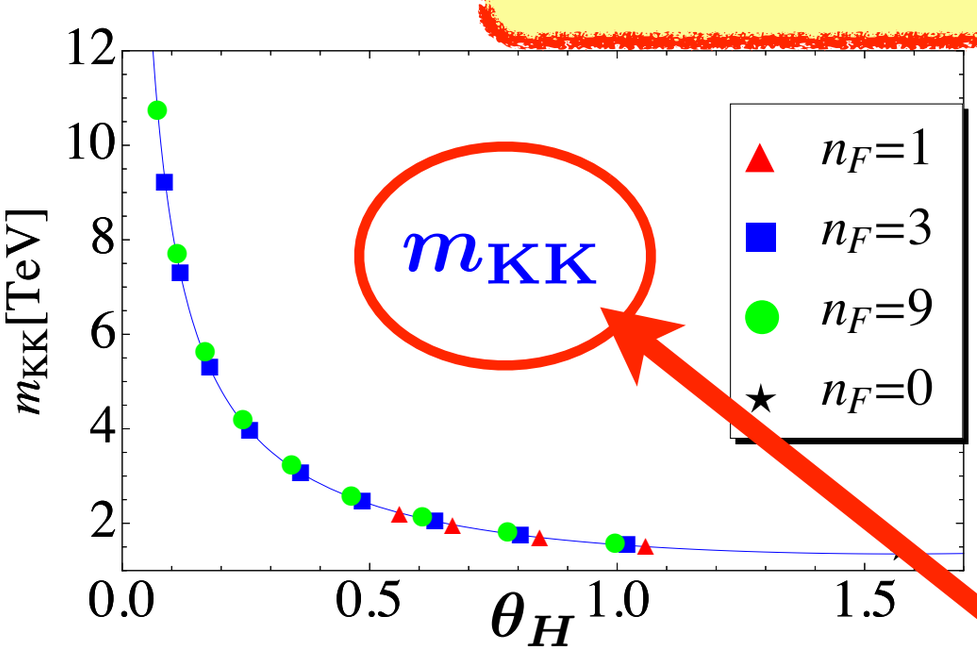
Higgs self couplings

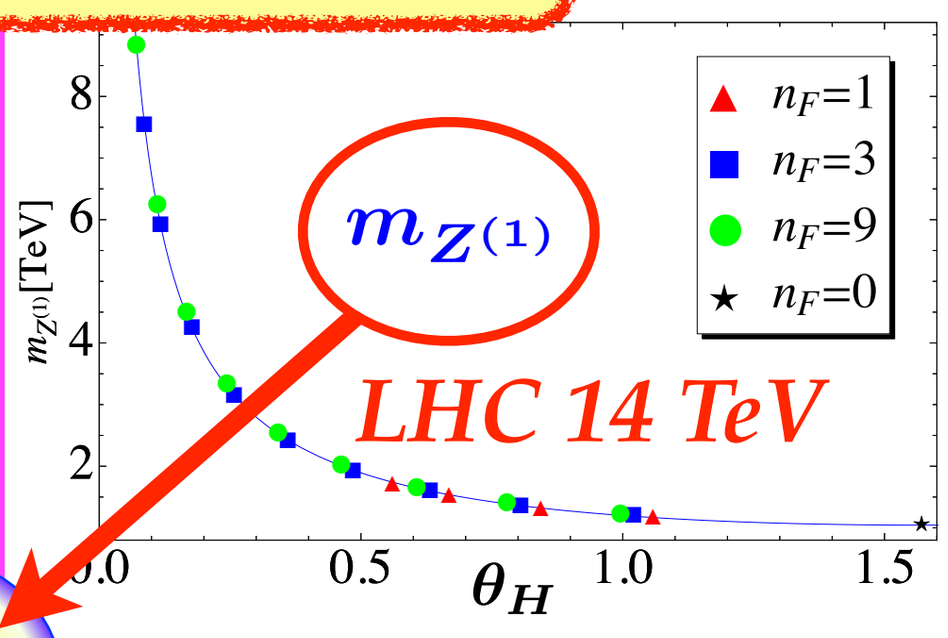




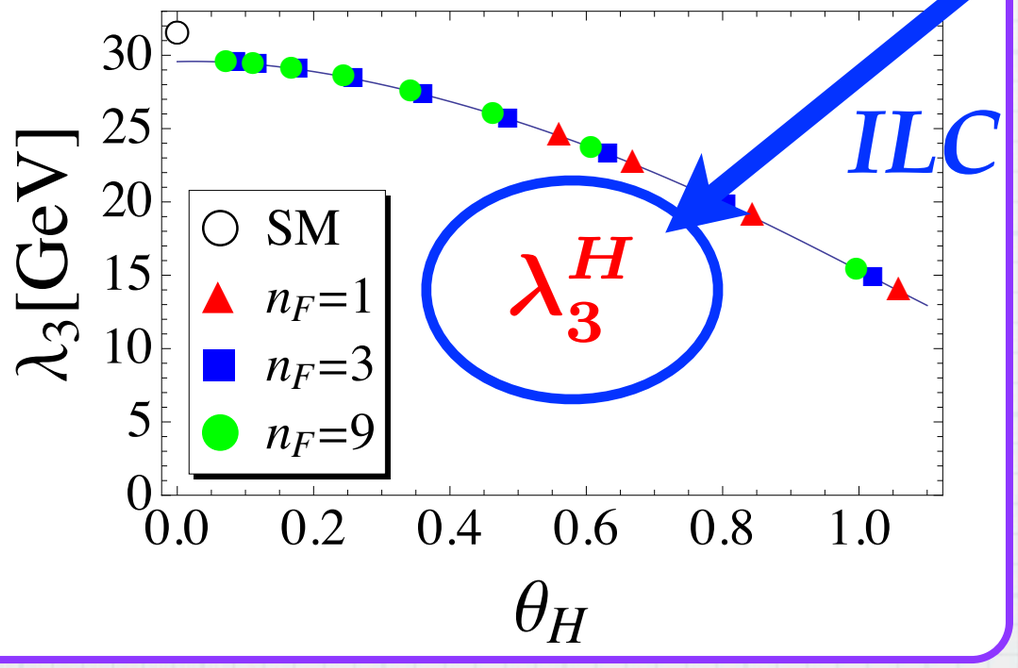
Universality

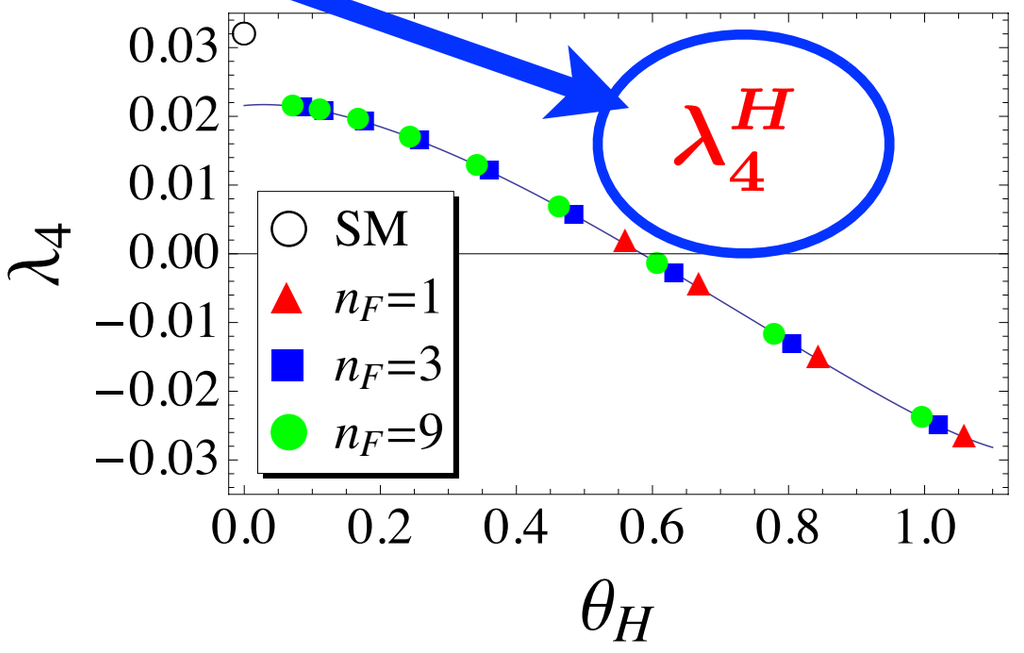
Universality predicts





θ_H





Physics
OSAKA UNIVERSITY

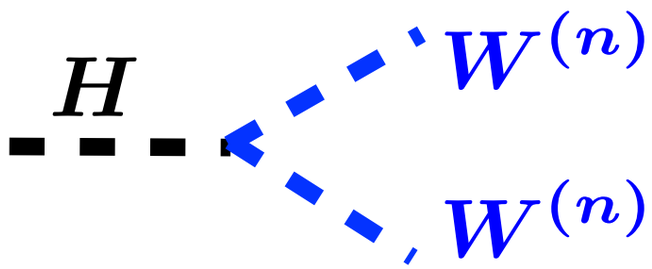
Higgs boson: Production and decay rates

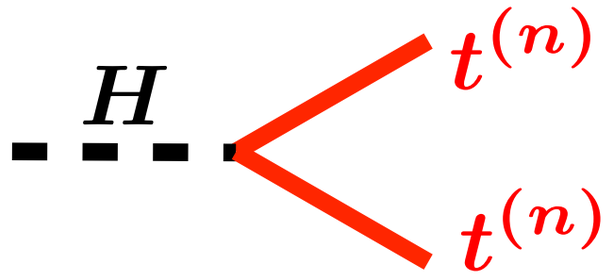
$$\left.\begin{matrix} WWH \\ ZZH \\ Yukawa \end{matrix}\right\} = SM \times \cos\theta_H$$

Suppression at tree level

$$gg \to H \quad , \quad H \to \gamma\gamma \, , \, gg$$

Enhanced or not ?





$$I_{W^{(n)}} = \frac{g_{HW^{(n)}W^{(n)}}}{g_w m_{W^{(n)}} \cos\theta_H}$$

$$I_{t^{(n)}} = \frac{y_{t^{(n)}}}{y_t^{\rm SM} \cos\theta_H}$$

For $\theta_H = 0.360$

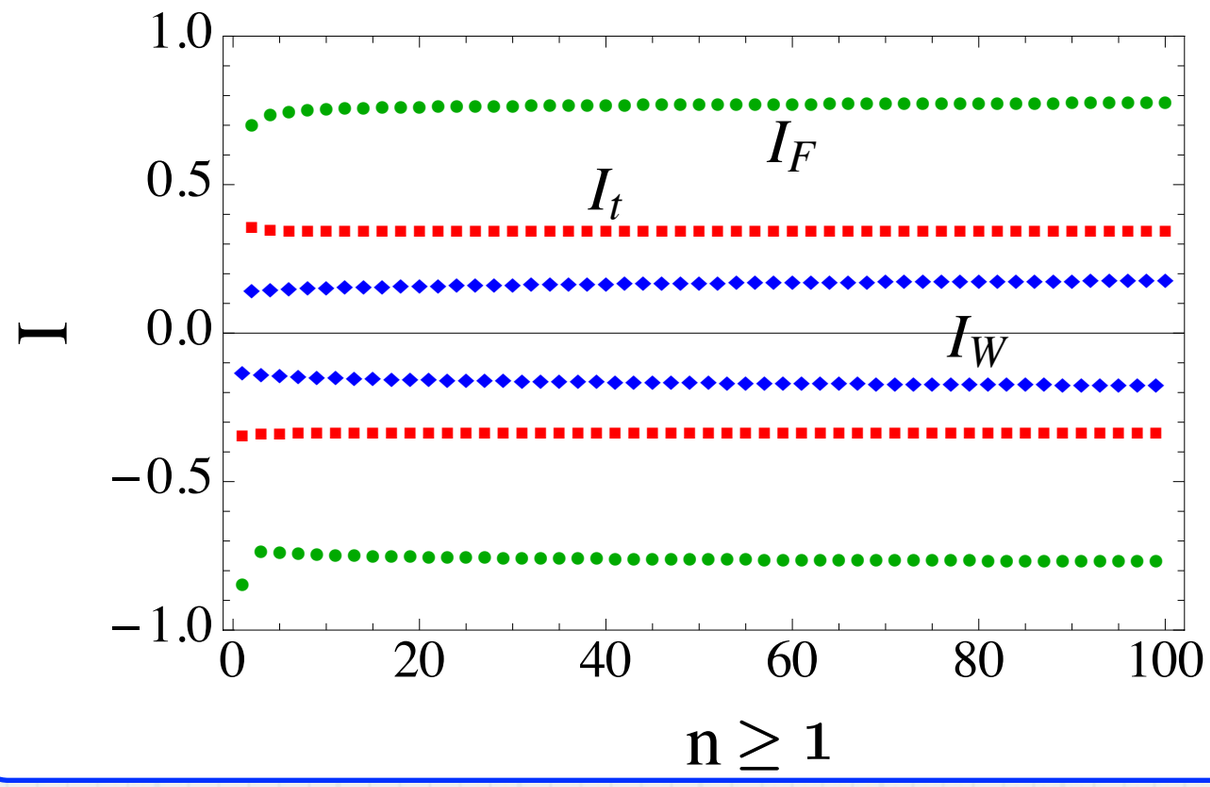
$I_{W^{(0)}} = 1.004$

$I_{t^{(0)}} = 1.012$

Sign alternates.

$n = 1, 2, 3, \ldots$

destructive interference



Maru, Okada, 2008
Falkowski, 2008

in sharp contrast to UED

Physics
OSAKA UNIVERSITY

$H \to \gamma\gamma$

$$\Gamma(H \to \gamma\gamma) = \frac{\alpha^2 g_w^2}{1024\pi^3} \frac{m_H^3}{m_W^2} \left| \mathcal{F}_{\rm total} \right|^2$$

$$\mathcal{F}_{\rm total} = \mathcal{F}_W + \frac{4}{3}\mathcal{F}_t + \frac{1}{2} n_F \mathcal{F}_F$$

θ_H	0.117	0.360
$\mathcal{F}_{W^{(0)}}$	8.330	7.873
$\mathcal{F}_W/\mathcal{F}_{W^{(0)}}$	0.9996	0.998
$\mathcal{F}_{t^{(0)}}$	-1.372	-1.305
$\mathcal{F}_t/\mathcal{F}_{t^{(0)}}$	0.998	0.990
$\mathcal{F}_F/\mathcal{F}_{t^{(0)}}$	-0.0034	-0.033
$\mathcal{F}_{\rm total}$	6.508	6.199
$\mathcal{F}_{\rm total}/(\mathcal{F}_{W^{(0)}} + \mathcal{F}_{t^{(0)}})$	1.001	1.011

Corrections due to KK W and top :

0.1 % - 1 % for θ_H = 0.1 - 0.3.

All decay rates $\Gamma(H \to b\bar{b}, c\bar{c}, \cdots, WW, ZZ, \gamma\gamma, gg)$

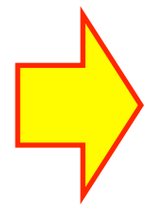
$$\sim \Gamma^{\rm SM} \times \cos^2 \theta_H$$

Branching fraction $B(H \to j) \sim B^{\rm SM}(H \to j)$

$$\sigma^{\rm prod}(H) \cdot B(H \to \gamma\gamma) \sim ({\rm SM}) \times \cos^2 \theta_H$$

$$0.99 \sim 0.91$$

S parameter
Tree unitarity
Z′ search



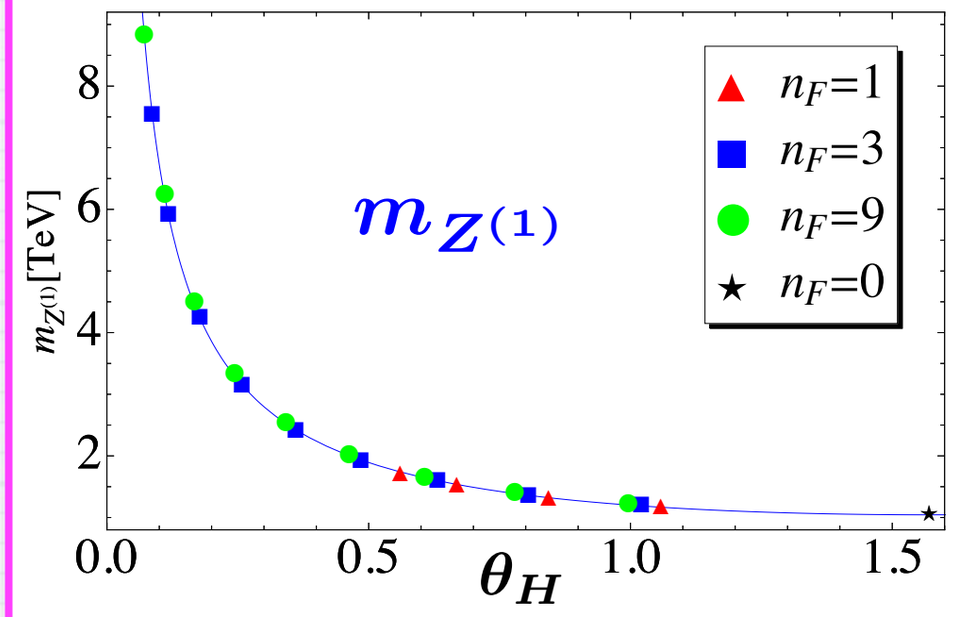
$$\theta_H < 0.3$$

Summary

SO(5)xU(1) Gauge-Higgs unification: promising

Universality

$\theta_H, m_{\rm KK}, \lambda_3^H, \lambda_4^H, m_{Z^{(1)}}$



Low energy physics : close to SM

Signals LHC/ILC

$Z^{(1)}$: $5.9 \sim 2.4\,\mathrm{TeV}$
$(\theta_H : 0.12 \sim 0.36)$

λ_3^H , λ_4^H

$F^{(1)}$, $\bar{F}^{(1)}$: stable
$(\mathrm{exp} : m_{F^{(1)}} > 0.5\,\mathrm{TeV})$