

$H \rightarrow \gamma\gamma, gg$

in the $SO(5) \times U(1)$ gauge-Higgs unification

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Gauge-Higgs Unification(GHU) model

motivation: hierarchy problem

extra dimensional
gauge field $A_y =$ Higgs field H

Hosotani mechanism

EW SSB by Wilson line phase θ_H

$$e^{i\theta_H} = P \exp \left\{ ig \int_0^{2\pi R} dy A_y \right\}$$

Y.Hosotani (1983), cf: H.Taniguchi's talk

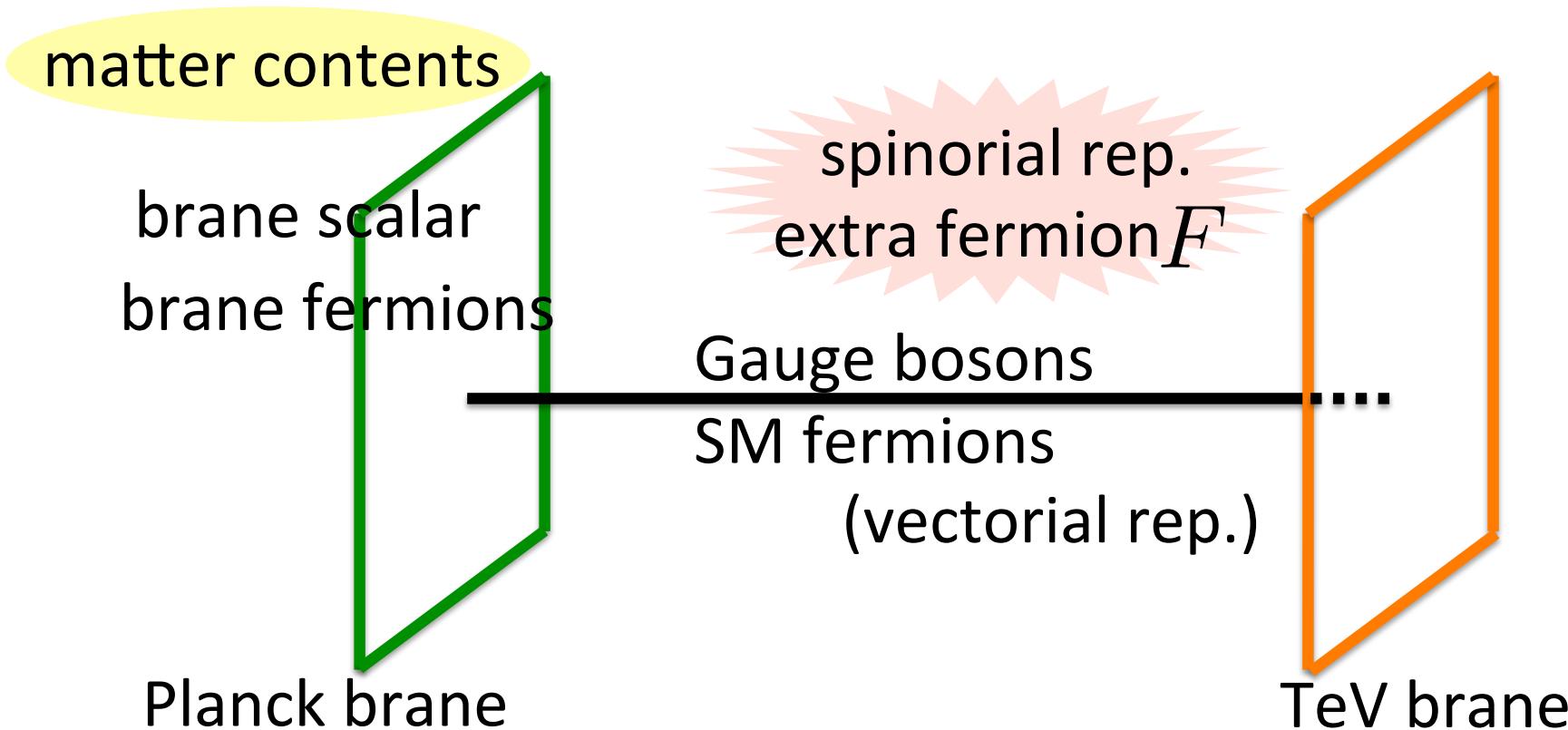
good points

1-loop effective potential (Higgs mass) is finite .
Higgs potential is given by the gauge principle.

$SO(5) \times U(1)$ GHU Model

K.Agashe, R.Contino, A.Pomarol(2005)
Y.Hosotani, K.Oda, T.Ohnuma, Y.Sakamura (2008)
Y.Hosotani, S.Noda, N.Uekusa (2009)
S.Funatsu, H.Hatanaka, Y.Hosotani, Y.Orikasa, T.S. (2013)

5-dim. Randall-Sundrum warped spacetime S^1/Z_2

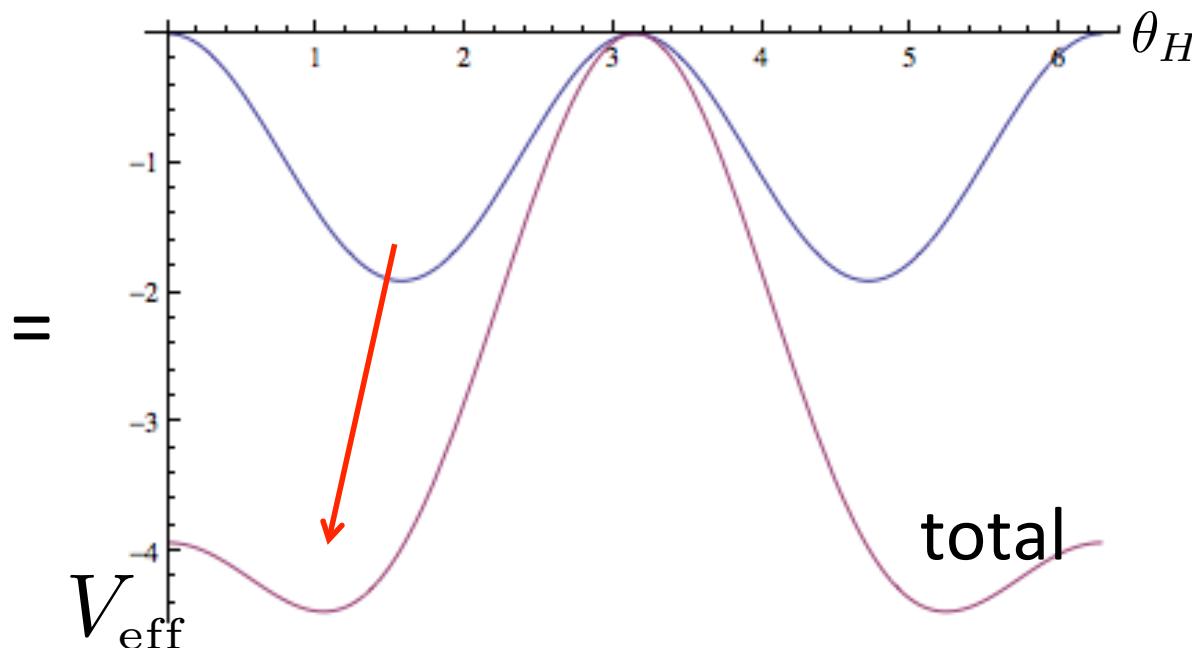
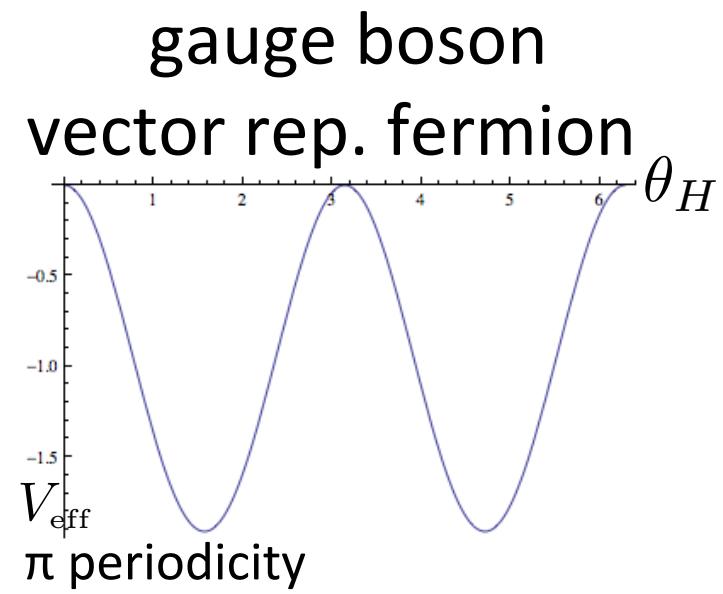
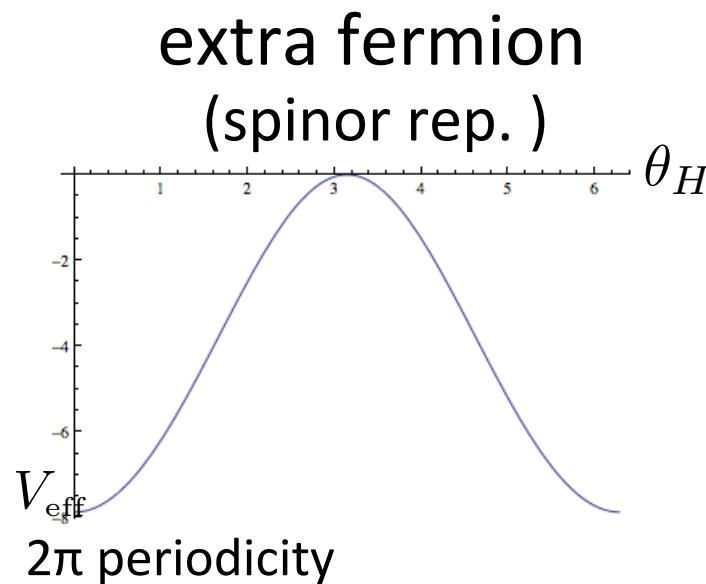


$$SO(5) \times U(1)_X$$

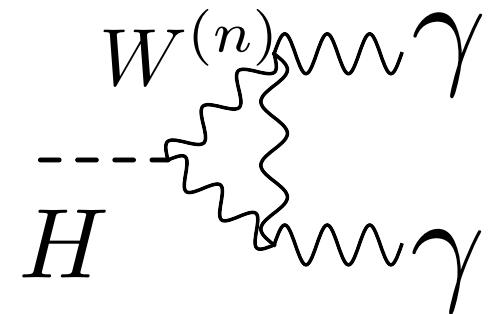
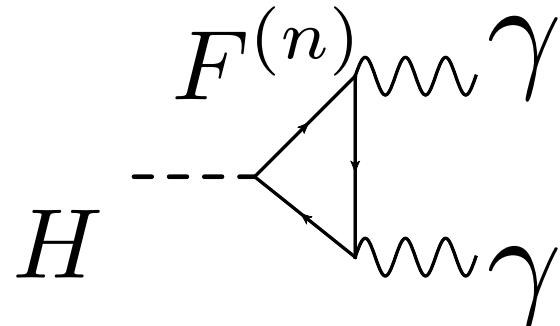
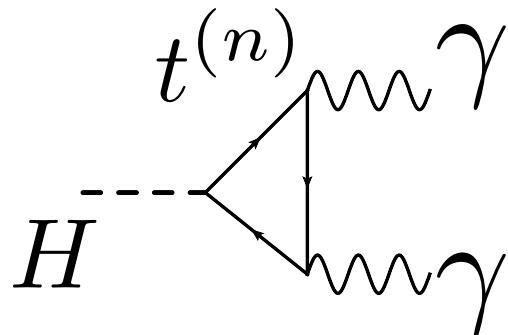
$$\xrightarrow{\text{B.C.}} SO(4) \times U(1)_X \xrightarrow{\text{brane scalar}} SU(2)_L \times U(1)_Y \rightarrow U(1)_{EM}$$

Hosotani mechanism

Effective potential



Higgs decay $H \rightarrow \gamma\gamma$



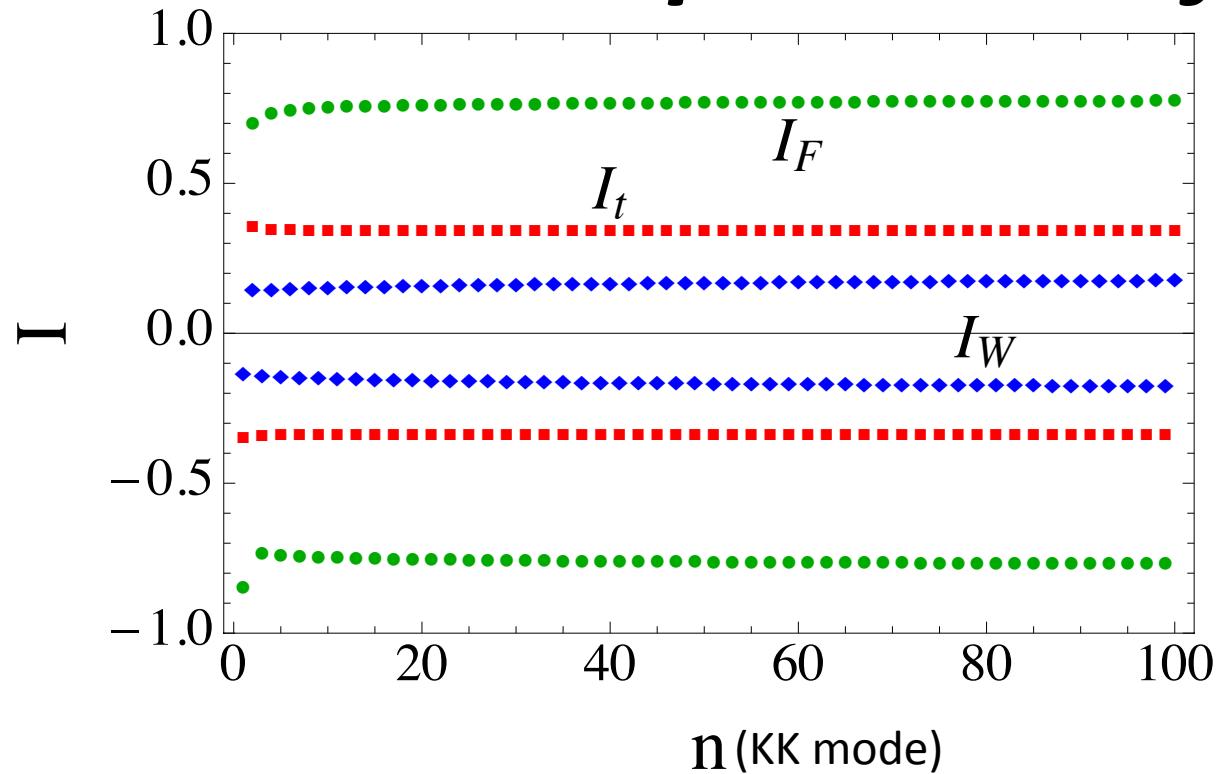
$$\Gamma(H \rightarrow \gamma\gamma) = \frac{\alpha^2 g_w^2}{1024\pi^3} \frac{m_H^3}{m_W^2} \left| \mathcal{A}_W + \frac{4}{3} \mathcal{A}_{\text{top}} + \frac{1}{2} n_F \mathcal{A}_F \right|^2$$

$$\mathcal{A}_W = \sum_{n=0}^{\infty} \frac{g_{HW^{(n)}W^{(n)}}}{g_w m_W} \frac{m_W^2}{m_{W^{(n)}}^2} F_1(\tau_{W(n)})$$

$$\mathcal{A}_{\text{top}} = \sum_{n=0}^{\infty} \frac{y_t^{(n)}}{y_t^{SM}} \frac{m_t}{m_{t^{(n)}}} F_{1/2}(\tau_{t(n)})$$

$$\mathcal{A}_F = \sum_{n=1}^{\infty} \frac{y_F^{(n)}}{y_t^{SM}} \frac{m_t}{m_{F^{(n)}}} F_{1/2}(\tau_{F(n)})$$

Amplitudes a finite!



$$\mathcal{A}_{\text{top}} = \sum_{n=0}^{\infty} \frac{y_t^{(n)}}{y_t^{SM}} \frac{m_t}{m_{t^{(n)}}} F_{1/2}(\tau_{t(n)}),$$

$$I_{t^{(n)}} = \frac{y_t^{(n)}}{y_t^{SM} \cos \theta_H}, \quad \tau_{t^{(n)}} = \frac{4m_{t^{(n)}}^2}{m_H^2}$$

The sign alternates
as n increases.

Convergence

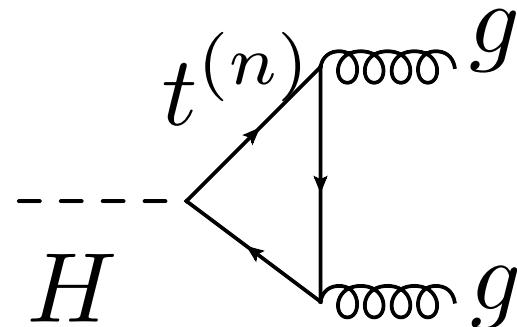
$$\sum_n (-1)^n n^{-1}$$

$$\frac{\mathcal{A}_{\text{total}}}{\mathcal{A}_{W^{(0)}} + \mathcal{A}_{\text{top}^{(0)}}} \sim 1.011 \text{ (1.001)}$$

$$\theta_H = 0.360 \text{ (0.117)}$$

Contribution of KK modes
are positive and small.

In a similar way, $H \rightarrow gg$, $gg \rightarrow H$



$$\Gamma(H \rightarrow gg) = \frac{\alpha^2 g_w^2}{128\pi^3} \frac{m_H^3}{m_W^2} \left| \mathcal{A}_{\text{top}} \right|^2$$

Decay rate and Signal strength

couplings (e.g. HWW, HZZ, yukawa)

$$g_{\text{GHU}} \sim g_{\text{SM}} \cos \theta_H$$

Higgs decay rates are suppressed by $\cos^2 \theta_H$

$$\theta_H = 0.360 \text{ (0.117)} \rightarrow \cos^2 \theta_H \sim 0.91 \text{ (0.99)}$$

$$\frac{\Gamma(H \rightarrow \gamma\gamma)_{\text{GHU}}}{\Gamma(H \rightarrow \gamma\gamma)_{\text{SM}}} = 0.93 \text{ (0.99)}$$

Signal strength

$$B(H \rightarrow X) = B^{\text{SM}}$$

$$\sigma^{\text{prod}} \cdot B(H \rightarrow X) \sim (\text{SM}) \times \cos^2 \theta_H$$

Summary

Decay rate and Signal strength in SO(5)×U(1) GHU

- Sign of couplings are alternate as n increases.
- Contributions of KK modes are small.
- Signal strength is close to SM value.

$$\frac{\Gamma(H \rightarrow \gamma\gamma)_{GHU}}{\Gamma(H \rightarrow \gamma\gamma)_{SM}} = 0.93 \text{ (0.99)}$$

$$\sigma^{\text{prod}} \cdot B(H \rightarrow X) \sim (SM) \times \cos^2 \theta_H$$

$0.91 \sim 0.99$

Work in Progress

Dark matter
Z' search

By C.K.
Up

$n_F = 3$ case

$m_H = 126\text{GeV}$

z_L	θ_H	m_{KK} (TeV)	k (GeV)	c_t	c_F	$m_{F^{(1)}}$ (TeV)	$m_{Z^{(1)}}$ (TeV)
10^{12}	1.02	1.54	4.90×10^{14}	0.413	0.476	0.155	1.19
10^{11}	0.805	1.75	5.56×10^{13}	0.403	0.454	0.232	1.36
10^{10}	0.632	2.03	6.47×10^{12}	0.391	0.433	0.329	1.59
10^9	0.485	2.45	7.79×10^{11}	0.376	0.411	0.465	1.93
10^8	0.360	3.05	9.72×10^{10}	0.357	0.385	0.668	2.41
10^7	0.258	3.95	1.26×10^{10}	0.330	0.353	0.993	3.15
10^6	0.177	5.30	1.69×10^9	0.296	0.309	1.54	4.25
10^5	0.117	7.29	2.32×10^8	0.227	0.235	2.53	5.91
2×10^4	0.086	9.21	5.87×10^7	0.137	0.127	3.88	7.54



Current data say,
 $m_Z^{(1)} > 2.5\text{TeV}$, $m_F^{(1)} > 0.5\text{TeV}$.

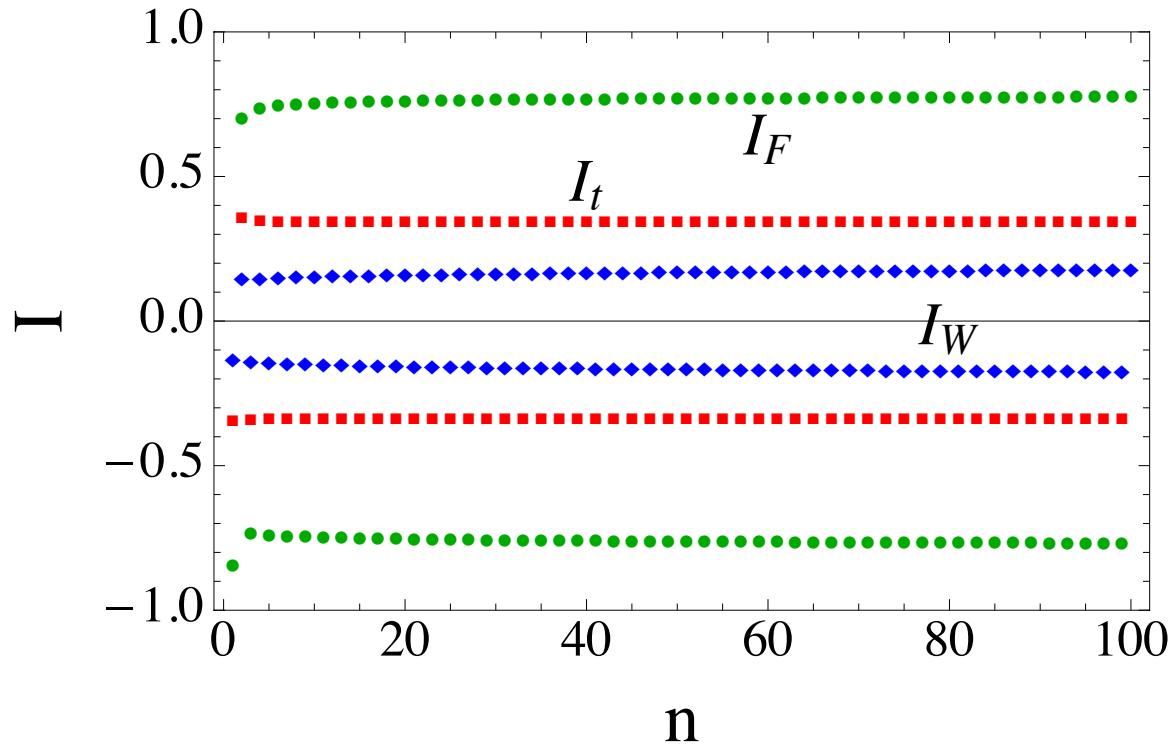
Contributions of amplitudes

$$\Gamma(H \rightarrow \gamma\gamma) = \frac{\alpha^2 g_w^2}{1024\pi^3} \frac{m_H^3}{m_W^2} \left| \mathcal{F}_W + \frac{4}{3} \mathcal{F}_{top} + \frac{1}{2} n_F \mathcal{F}_F \right|^2$$

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

For KK W

Amplitudes a finite!



$$\tau_a = 4m_a^2/m_H^2$$

$$\tau_a \rightarrow \infty$$

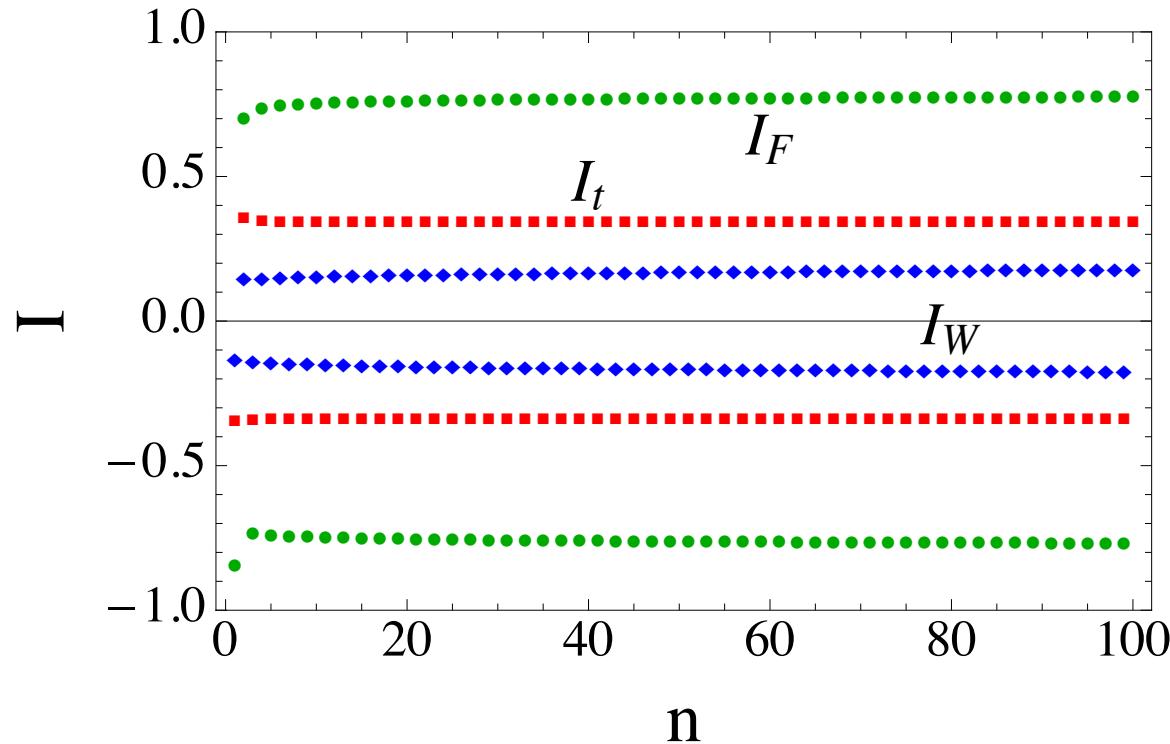
$$F_1(\tau_a) \rightarrow 7$$

$$\mathcal{A}_W = \sum_{n=0}^{\infty} \frac{g_{HW^{(n)}W^{(n)}}}{g_w m_W} \frac{m_W^2}{m_{W^{(n)}}^2} F_1(\tau_{W^{(n)}})$$

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

For KKF

Amplitudes a finite!



$$\tau_a = 4m_a^2/m_H^2$$

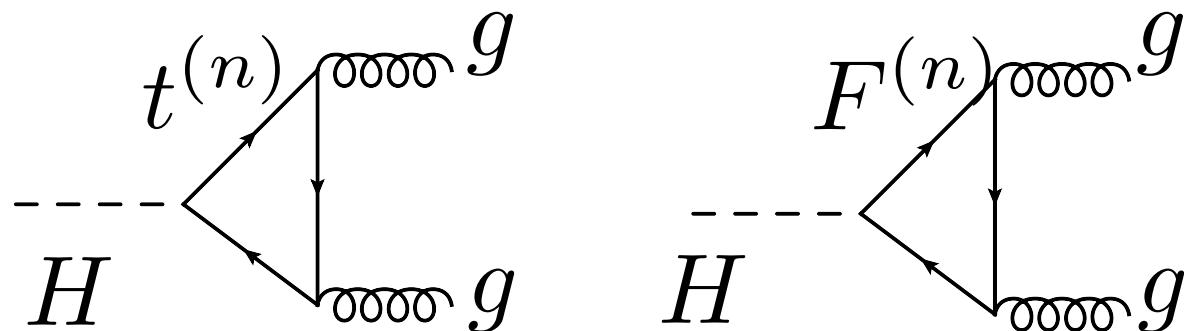
$$\tau_a \rightarrow \infty$$

$$F_{1/2}(\tau_a) \rightarrow -\frac{4}{3}$$

$$\mathcal{A}_F = \sum_{n=1}^{\infty} \frac{y_F^{(n)}}{y_t^{SM}} \frac{m_t}{m_{F^{(n)}}} F_{1/2}(\tau_{F(n)})$$

$$I_{F^{(n)}} = \frac{y_{F^{(n)}}}{y_t^{SM} \sin \frac{1}{2}\theta_H}$$

Color triplet case $H \rightarrow gg$, $gg \rightarrow H$



$$\Gamma(H \rightarrow gg) = \frac{\alpha^2 g_w^2}{128\pi^3} \frac{m_H^3}{m_W^2} \left| \mathcal{A}_{\text{top}} + \frac{2}{3} n_F \mathcal{A}_F \right|^2$$

Decay rate

couplings (e.g. HWW, HZZ, yukawa)

$$g_{\text{GHU}} \sim g_{\text{SM}} \cos \theta_H$$

Higgs decay rates are suppressed by $\cos^2 \theta_H$.

$0.99 \sim 0.91$

For $n_F=3$, $\theta_H=0.360$ (0.117)

Compared to the value in the SM,
 $\Gamma(H \rightarrow \gamma\gamma)$ is **suppressed 10 % (1 %)**

including contributions of KK mode
2%(0.2%).

Signal strength

Contributions of KK mode are small.

All Higgs decay rates are suppressed by $\cos^2 \theta_H$.



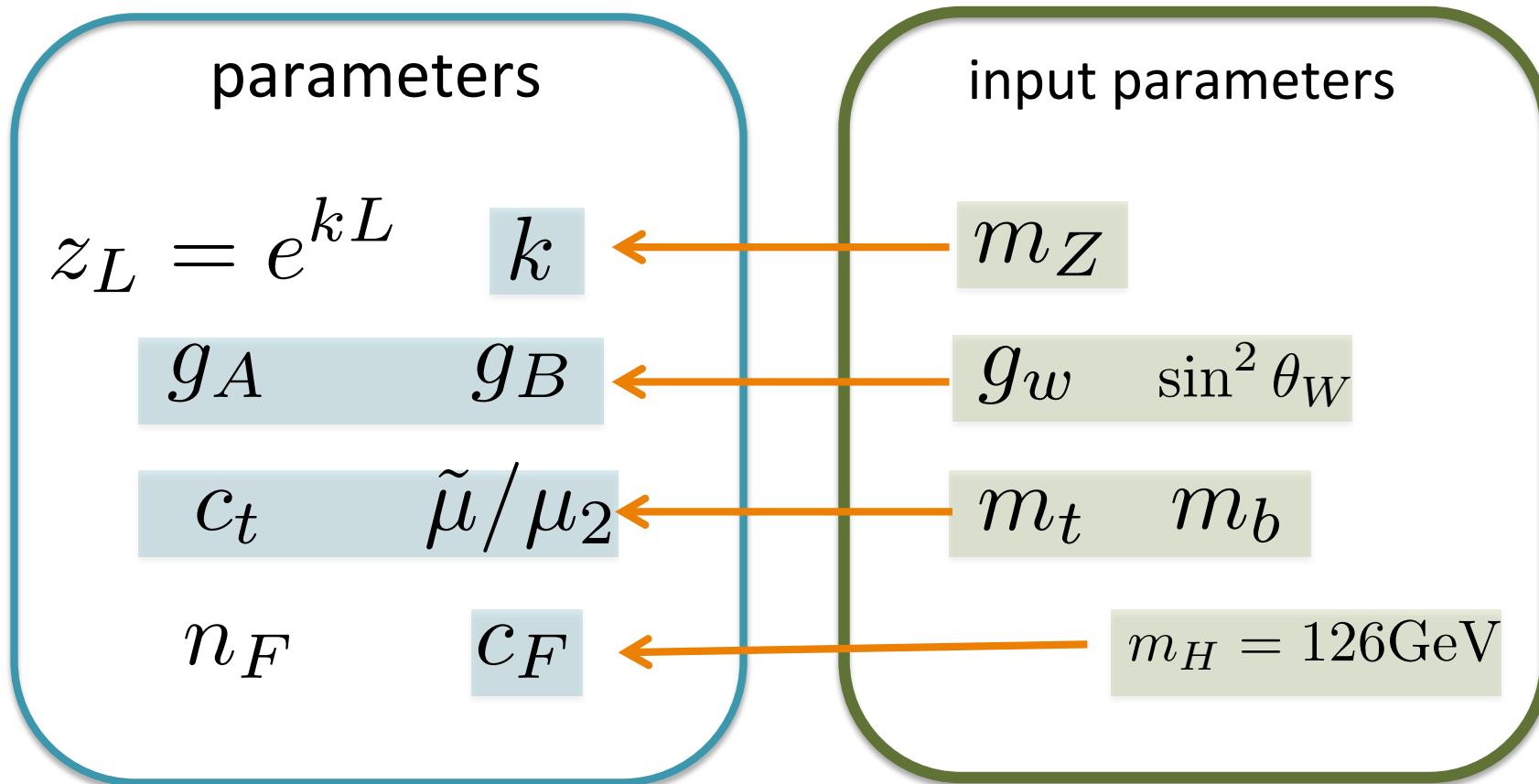
Branching fractions are not suppressed by $\cos^2 \theta_H$.

The GHU model predicts

observed event rate $\sigma^{\text{prod}} \cdot B(H \rightarrow \gamma\gamma)$

relative to the SM is $\sim \cos^2 \theta_H$
 $0.99 \sim 0.91$

parameters



We have only 2 degrees of freedom.

$z_L \quad n_F$