Collider Signatures of Gauge-Higgs Unification at LHC

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3/12/2014 Seminar@Nagoya

References

- 125 GeV Higgs Boson and TeV Scale Colored Fermions in Gauge-Higgs Unification, arXiv:1310.3348
- Diphoton and Z photon Decays of Higgs Boson in Gauge-Higgs Unification: A Snowmass white paper arXiv: 1307:8181
- H→Zγ in Gauge-Higgs Unification, PRD88 037701 (2013)
- Diphoton Decay Excess and 125 GeV Higgs Mass in Gauge-Higgs Unification, PRD87 095019 (2013)
- Gauge-Higgs Unification at CERN LHC, PRD77 055010 (2008)

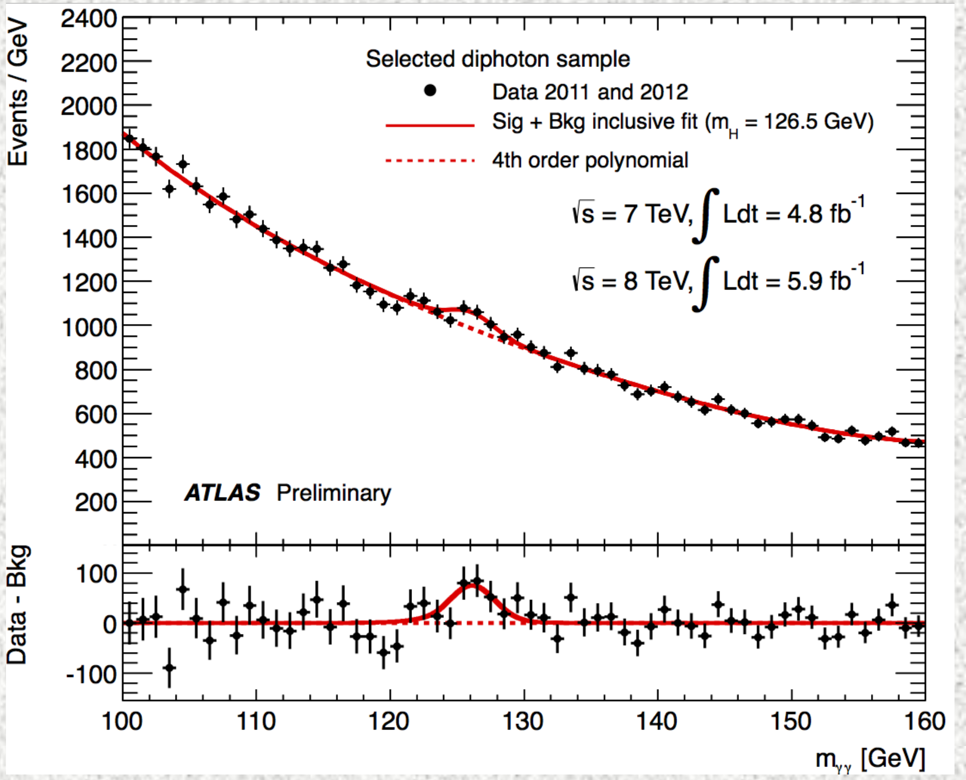
All papers with Nobuchika Okada

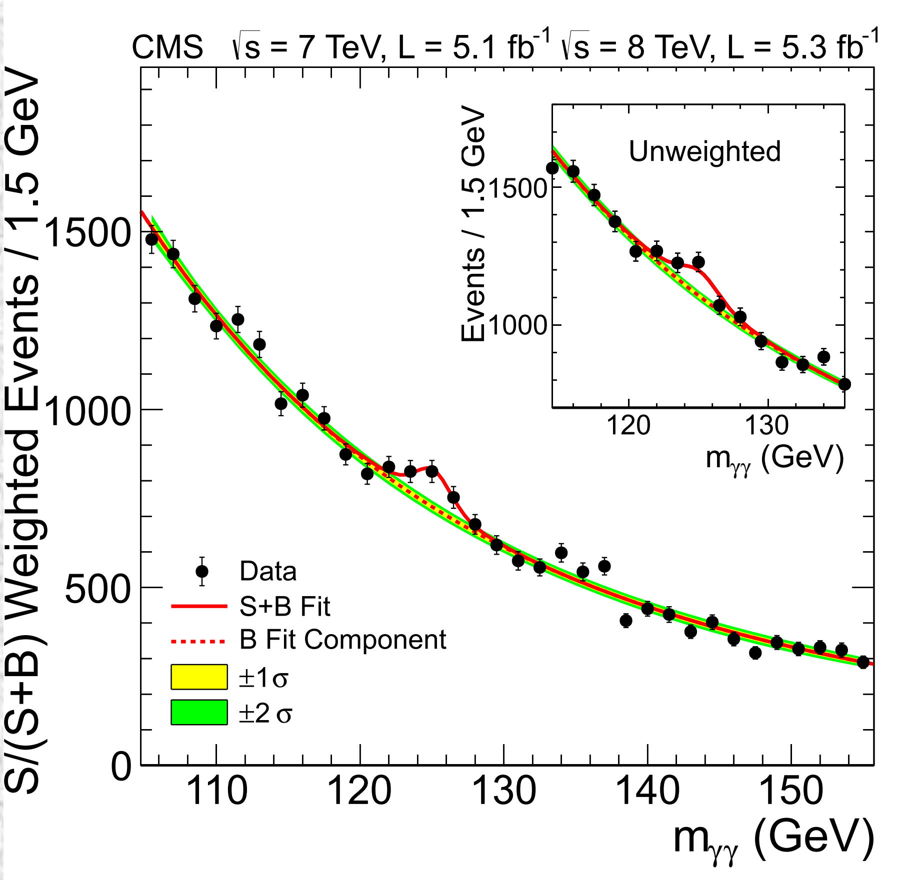
PLAN

- Introduction
- A Model of GHU
- $gg \to H$ & $H \to \gamma\gamma$ in GHU
- $H \to Z\gamma$
- Summary

Introduction

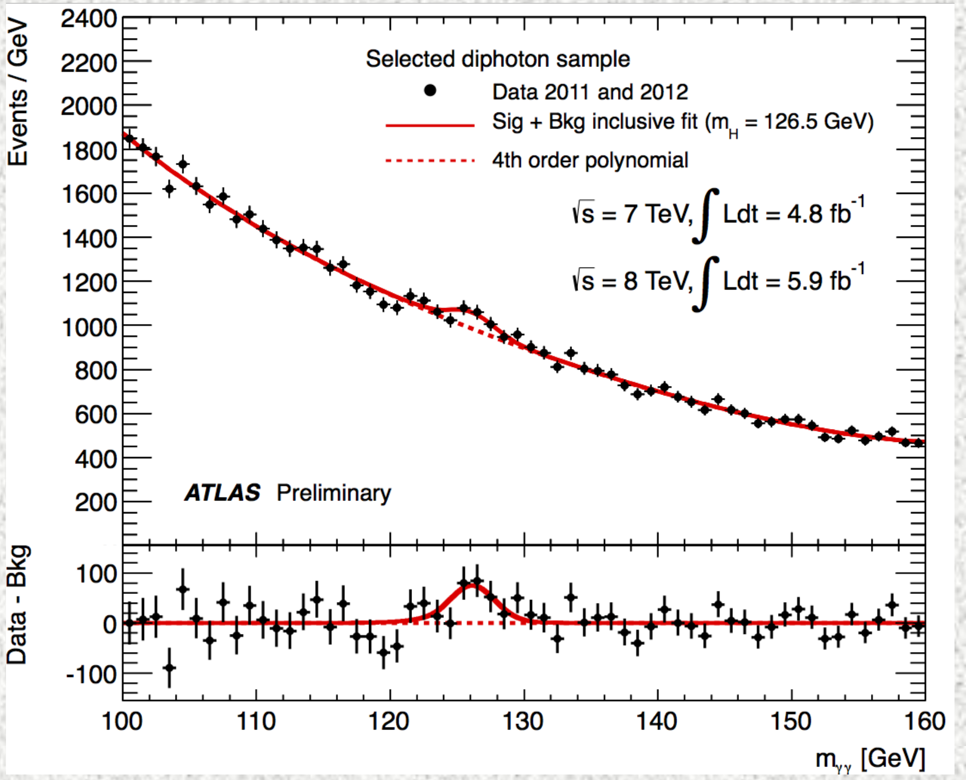
A Higgs boson was discovered!!

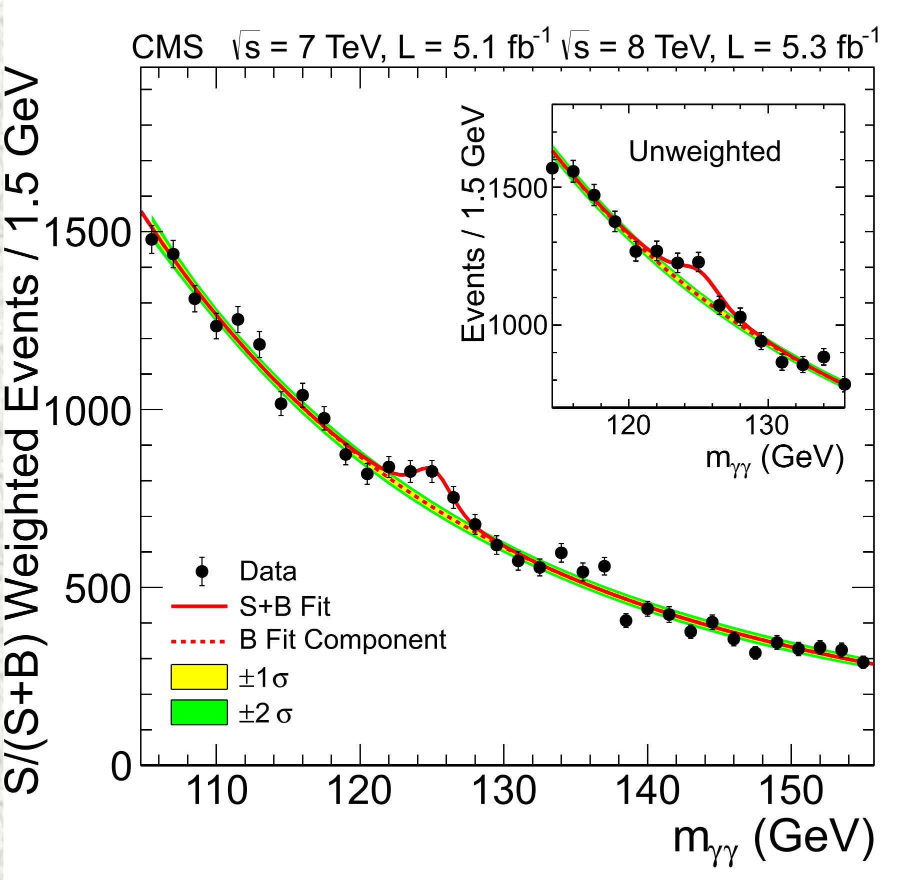




Introduction

Still unclear, the origin of Higgs ??





taken from Grojean's slides

In the gauge-Higgs unification,

1: New structure in the Higgs sector
2: Coupling of new particles to Higgs boson

controlled by higher dimensional gauge invariance

Deviations from the SM predictions &
Collider signatures specific to GHU
are expected!!

A Model of GHU

Lagrangian

5D SU(3) x U(1)′ model on S^1/Z_2

$$\mathcal{L} = -\frac{1}{2}\mathrm{Tr}\left(F_{MN}F^{MN}\right) + \bar{\Psi}_{3}^{i=1,2,3}\left(i\Gamma^M D_M - M_d^i \varepsilon(y)\right)\Psi_{3}^{i=1,2,3}$$
$$+ \bar{\Psi}_{\bar{6}}^{i=1,2}\left(i\Gamma^M D_M - M_u^i \varepsilon(y)\right)\Psi_{\bar{6}}^{i=1,2} + \bar{\Psi}_{\overline{15}} i\Gamma^M D_M \Psi_{\overline{15}}$$
$$+ \bar{\Psi}_{10}^{i=1,2,3}\left(i\Gamma^M D_M - M_l^i \varepsilon(y)\right)\Psi_{10}^{i=1,2,3} \qquad \Gamma^M = \left(\gamma^\mu, i\gamma^5\right)$$

Boundary conditions:

S^1: $\Psi(y+2\pi R) = \psi(y)$, Z_2: $\Psi(-y) = \pm\psi(y)$

$$A_\mu = \begin{pmatrix} (+,+) & (+,+) & (-,-) \\ (+,+) & (+,+) & (-,-) \\ (-,-) & (-,-) & (+,+) \end{pmatrix}, A_5 = \begin{pmatrix} (-,-) & (-,-) & (+,+) \\ (-,-) & (-,-) & (+,+) \\ (+,+) & (+,+) & (-,-) \end{pmatrix}$$

Lagrangian

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$$+ \bar{\Psi}_{\bar{6}}^{i=1,2}\left(i\Gamma^M D_M - M_u^i \varepsilon(y)\right)\Psi_{\bar{6}}^{i=1,2} + \bar{\Psi}_{\overline{15}} i\Gamma^M D_M \Psi_{\overline{15}}$$

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Boundary conditions:

(+,+) only has massless mode

(+,+): cos(ny/R)
(-,-): sin(ny/R)

$$A_\mu = \begin{pmatrix} (+,+) & (+,+) & (-,-) \\ (+,+) & (+,+) & (-,-) \\ (-,-) & (-,-) & (+,+) \end{pmatrix}, A_5 = \begin{pmatrix} (-,-) & (-,-) & (+,+) \\ (-,-) & (-,-) & (+,+) \\ (+,+) & (+,+) & (-,-) \end{pmatrix}$$

Lagrangian

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$SU(3) \times U(1)' \rightarrow SU(2) \times U(1)_Y \times U(1)_X$

Lagrangian

5D SU(3) x U(1)' model on S^1/Z_2

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0 mode of A_5 = SM Higgs

Minimal Fermion matter content

$\mathbf{3} = \mathbf{2}_{L1/6}(Q) + \mathbf{1}_{L-1/3}$
$\quad\;\; \mathbf{2}_{R1/6} + \mathbf{1}_{R-1/3}(d_R)$

Down quark sector

$\mathbf{6^*} = \mathbf{3}_{L-1/3} + \mathbf{2}_{L1/6}(Q) + \mathbf{1}_{L2/3}$
$\quad\;\; \mathbf{3}_{R-1/3} + \mathbf{2}_{R1/6} + \mathbf{1}_{R2/3}(u_R)$

Up quark sector (except for top)

$\mathbf{10} = \mathbf{4}_{L1/2} + \mathbf{3}_{L0} + \mathbf{2}_{L-1/2}(L) + \mathbf{1}_{L-1}$
$\quad\;\; \mathbf{4}_{R1/2} + \mathbf{3}_{R0} + \mathbf{2}_{R-1/2} + \mathbf{1}_{R-1}(e_R)$

Charged lepton sector

$\mathbf{15^*} = \mathbf{5}_{L-4/3} + \mathbf{4}_{L-5/6} + \mathbf{3}_{L-1/3} + \mathbf{2}_{L1/6}(Q) + \mathbf{1}_{L2/3}$
$\quad\;\; \mathbf{5}_{R-4/3} + \mathbf{4}_{R-5/6} + \mathbf{3}_{R-1/3} + \mathbf{2}_{R1/6} + \mathbf{1}_{R2/3}(t_R)$

Top quark

Unwanted massless exotics (blue reps) & two extra Qs must be massive by brane localized mass terms

Big Hurdle

In the gauge-Higgs unification,

Yukawa coupling = gauge coupling

How can we get fermion mass hierarchy???

⬇

Localizing fermions@different point in 5th direction

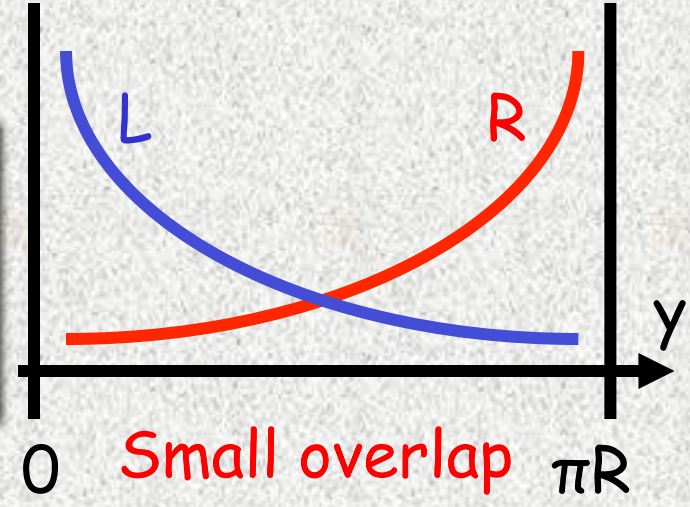
Yukawa ~ exponentially suppressed overlap integral of wave functions

Arkani-Hamed & Schmaltz (1999)

Zero mode wave functions

$$0=\left[\partial_y + M\varepsilon(y)\right] f_L^{(0)}(y) \rightarrow f_L^{(0)}(y)=\sqrt{\frac{M}{1-e^{-2\pi MR}}}e^{-M|y|}$$

$$0=\left[\partial_y - M\varepsilon(y)\right] f_R^{(0)}(y) \rightarrow f_R^{(0)}(y)=\sqrt{\frac{M}{e^{2\pi MR}-1}}e^{M|y|}$$



4D effective Yukawa coupling

$$Y = g_4 \int_{-\pi R}^{\pi R} dy f_L^{(0)}(y) f_R^{(0)}(y) = g_4 \int_{-\pi R}^{\pi R} dy \sqrt{\frac{M^2}{\left(1-e^{-2\pi MR}\right)\left(e^{2\pi MR}-1\right)}}$$

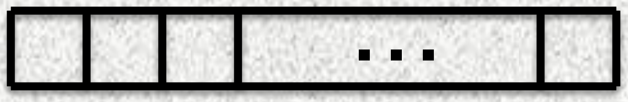
$$\approx 2\pi MR g_4 e^{-\pi MR} \leq g_4 \left(\pi MR \gg 1\right) \Leftrightarrow m_f \leq m_W$$

Fermion masses except top is easy to obtain by tuning M
Top in 15* rep ⇒ factor "2" enhancement

Martinelli, Salvatori, Scrucca & Silvestrini (2005)

$\sqrt{N}$ enhancement

Consider a rank N symmetric tensor of SU(3)



N boxes

Decompose it into SU(2) reps as 3 = 2 + 1
and make a singlet & a doublet

singlet


unique

doublet


etc N patterns

Canonical kinetic term ⇒ 1/sqrt[N]

Yukawa = $1_R\, 2_L\, 2_H$ ⇒ N x 1/sqrt[N] = sqrt[N]

Essential Points for calculation (Specific form of KK masses in GHU)

Mass splitting & Coupling to Higgs

KK top

$$m_t^{+(n)} = \frac{n}{R} + m_t \qquad - \frac{m_t}{v} h$$

$$m_t^{-(n)} = \frac{n}{R} - m_t \qquad + \frac{m_t}{v} h$$

KK W

$$m_W^{+(n)} = \frac{n}{R} + m_W \qquad + \frac{m_W m_W^{+(n)}}{v} h$$

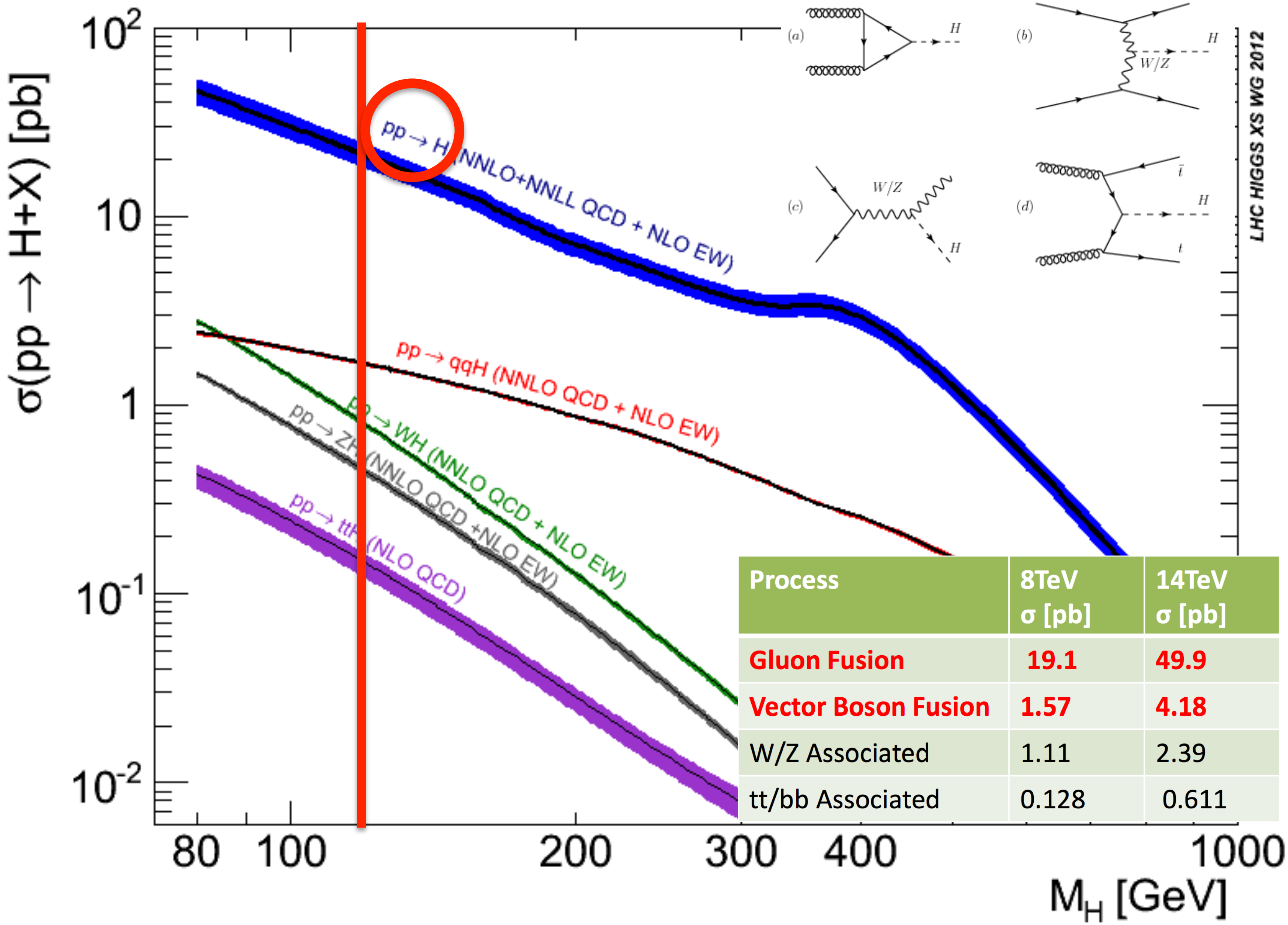
$$m_W^{-(n)} = \frac{n}{R} - m_W \qquad - \frac{m_W m_W^{-(n)}}{v} h$$

Characteristic predictions to "finite" $gg \to H$, $H \to \gamma\gamma$ amplitudes

MN & Okada (2007), NM(2008)

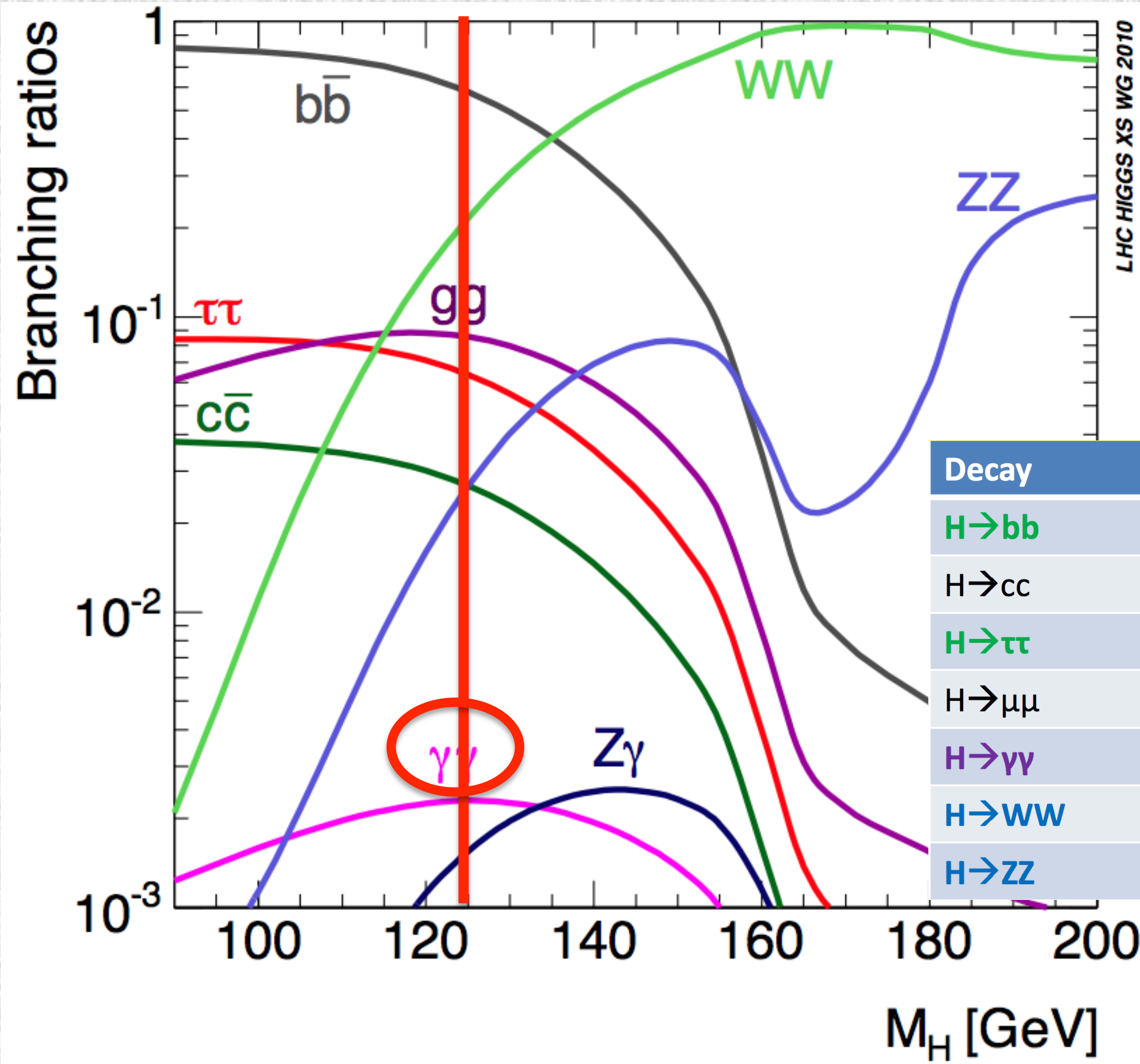
$gg \to H$ & $H \to \gamma\gamma$ in GHU

Higgs production



Process	8TeV σ [pb]	14TeV σ [pb]
Gluon Fusion	**19.1**	**49.9**
Vector Boson Fusion	**1.57**	**4.18**
W/Z Associated	1.11	2.39
tt/bb Associated	0.128	0.611

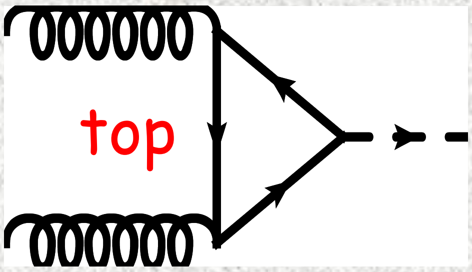
Decay rate of Higgs boson



Decay	Branch in percent
H→bb	57 %
H→cc	2.9%
H→ττ	6.2%
H→μμ	0.02%
H→γγ	0.23%
H→WW	22%
H→ZZ	2.8%

SM contributions

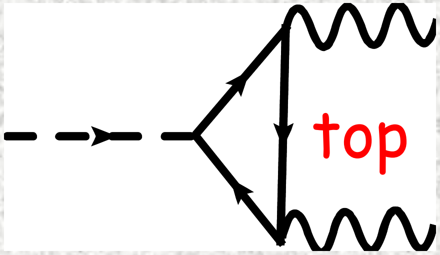
gg -> H

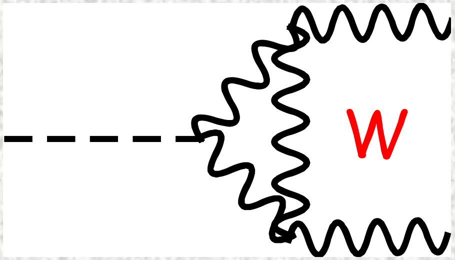


$$\mathcal{L}_{eff} = C_{gg}^{SM} h G^{a\mu\nu} G_{\mu\nu}^{a}$$

$$C_{gg}^{SM} = \frac{\alpha_s}{8\pi v} b_3^t \frac{\partial \ln m_t}{\partial \ln v} = \frac{\alpha_s}{12\pi v}$$

H -> γγ





$$\mathcal{L}_{eff} = C_{\gamma\gamma}^{SM} h F^{\mu\nu} F_{\mu\nu}$$

$$C_{\gamma\gamma}^{SM} = C_{\gamma\gamma}^{top} + C_{\gamma\gamma}^{W} = -\frac{47\alpha_{em}}{72\pi v}$$

$$C_{\gamma\gamma}^{top} = \frac{\alpha_{em}}{6\pi v} \frac{4}{3} \frac{\partial \ln m_t}{\partial \ln v} = \frac{2\alpha_{em}}{9\pi v}$$

$$C_{\gamma\gamma}^{W} = \frac{\alpha_{em}}{8\pi v} (-7) \frac{\partial \ln m_W}{\partial \ln v} = -\frac{7\alpha_{em}}{8\pi v}$$

Higgs Low Energy Theorem

Coefficient of dim 5 operater $hG^a_{\mu\nu}G^{a\mu\nu}$ can be extracted from 1-loop RGE of gauge coupling

Gauge kinetic term

$$\mathcal{L} = -\frac{1}{4g^2(\mu)} G^a_{\mu\nu} G^{a\mu\nu}$$

β-function coefficient below and above M(v)

1-loop RGE

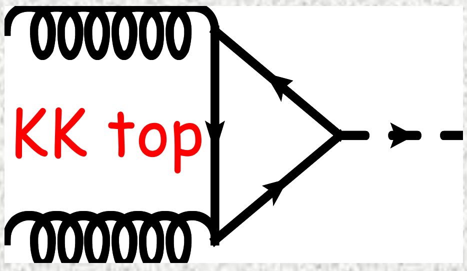
$$\frac{1}{g^2(\mu)} = \frac{1}{g^2(\Lambda)} + \frac{b_3}{8\pi^2}\ln\frac{\Lambda}{\mu} + \frac{\Delta b_3}{8\pi^2}\ln\frac{\Lambda}{M(v)}$$

Higgs VEV dependent threshold

Under $v \to v + h$, and extracting $O(h)$ term, we find

$$\mathcal{L}_{eff} = \frac{\Delta b_3}{32\pi^2}\left(\frac{\partial}{\partial v}\ln M(v)\right) h G^a_{\mu\nu} G^{a\mu\nu}$$

KK mode contributions: gg → H



$$\mathcal{L}_{eff} = C_{gg}^{KK} h G^{a\mu\nu} G_{\mu\nu}^{a}$$

$$C_{gg}^{KKtop} = \frac{\alpha_S}{8\pi v}\frac{2}{3}\sum_{n=1}^{\infty}\frac{\partial}{\partial \ln v}\left[\ln\left(m_n + m_t\right) + \ln\left(m_n - m_t\right)\right]$$

$m_n = n/R$

$$= \frac{\alpha_S}{12\pi v}\sum_{n=1}^{\infty}\left[\frac{m_t}{m_n + m_t} - \frac{m_t}{m_n + m_t}\right]$$

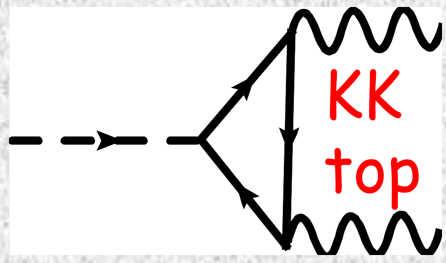
log∞ - log∞ = finite

$$\cong -\frac{\alpha_S}{12\pi v} 2\sum_{n=1}^{\infty}\frac{m_t^2}{m_n^2}\left(m_t^2 \ll m_n^2\right) = -\frac{\alpha_S}{12\pi v}\frac{1}{3}\left(\pi m_t R\right)^2$$

Opposite sign to SM ⇒ destructive

KK mode contributions: $H \to \gamma\gamma$

$$\mathcal{L}_{eff} = C_{\gamma\gamma}^{KK} h F^{\mu\nu} F_{\mu\nu}$$



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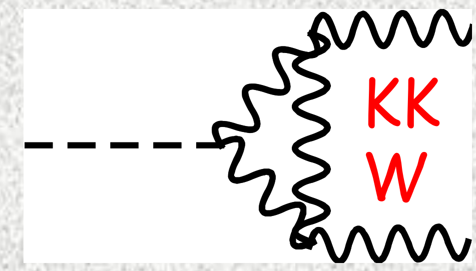


$$C_{\gamma\gamma}^{KKtop} = \frac{\alpha_{em}}{6\pi v}\frac{4}{3}\sum_{n=1}^{\infty}\frac{\partial}{\partial \ln v}\left[\ln\left(m_n + m_t\right) + \ln\left(m_n - m_t\right)\right]$$

$$\cong -\frac{2\alpha_{em}}{9\pi v}\frac{1}{3}\left(\pi m_t R\right)^2$$ Opposite sign to SM

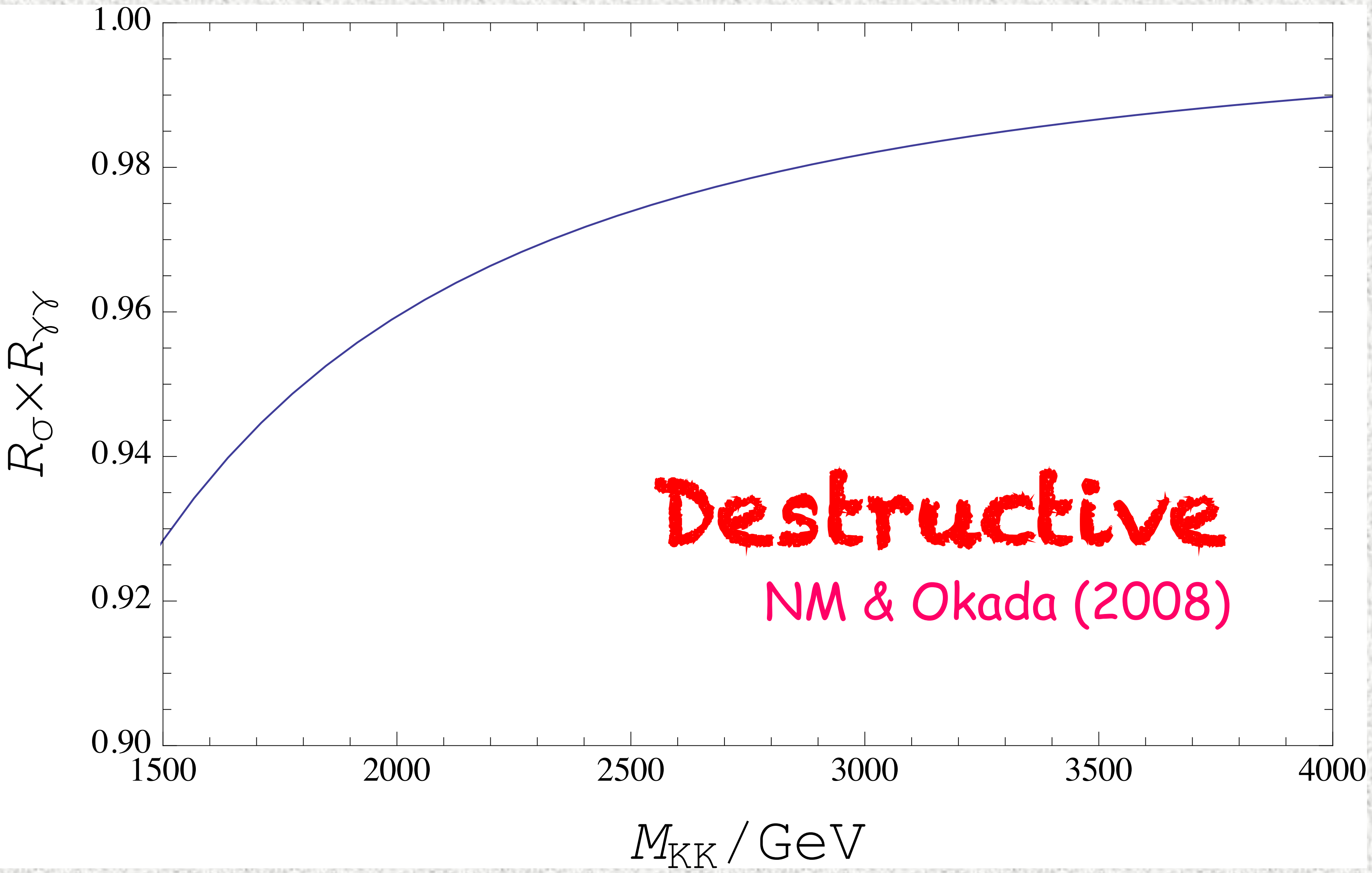
$$C_{\gamma\gamma}^{KKW} = \frac{\alpha_{em}}{8\pi v}\left(-7\right)\sum_{n=1}^{\infty}\frac{\partial}{\partial \ln v}\left[\ln\left(m_n + m_W\right) + \ln\left(m_n - m_W\right)\right]$$

$$\cong +\frac{7\alpha_{em}}{8\pi v}\frac{1}{3}\left(\pi m_W R\right)^2$$ Opposite sign to SM

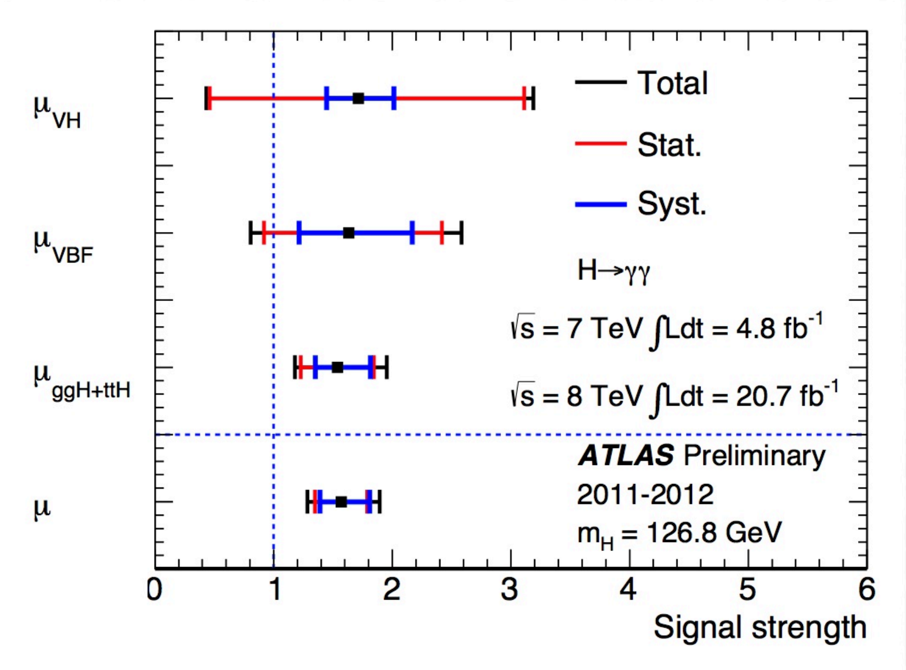
	$gg \to H$	$H \to \gamma\gamma$
Top	$\frac{\alpha_S}{12\pi v}$	$\frac{2\alpha_{em}}{9\pi v}$
W		$-\frac{7\alpha_{em}}{8\pi v}$
KK Top	$-\frac{\alpha_S}{12\pi v}\frac{1}{3}(\pi m_t R)^2$	$-\frac{2\alpha_{em}}{9\pi v}\frac{1}{3}(\pi m_t R)^2$
KK W		$\frac{7\alpha_{em}}{8\pi v}\frac{1}{3}(\pi m_W R)^2$
GHU/SM	$1-\frac{1}{3}(\pi m_t R)^2$	$1+\frac{1}{141}(\pi m_W R)^2$

KK mode contributions: opposite sign!!

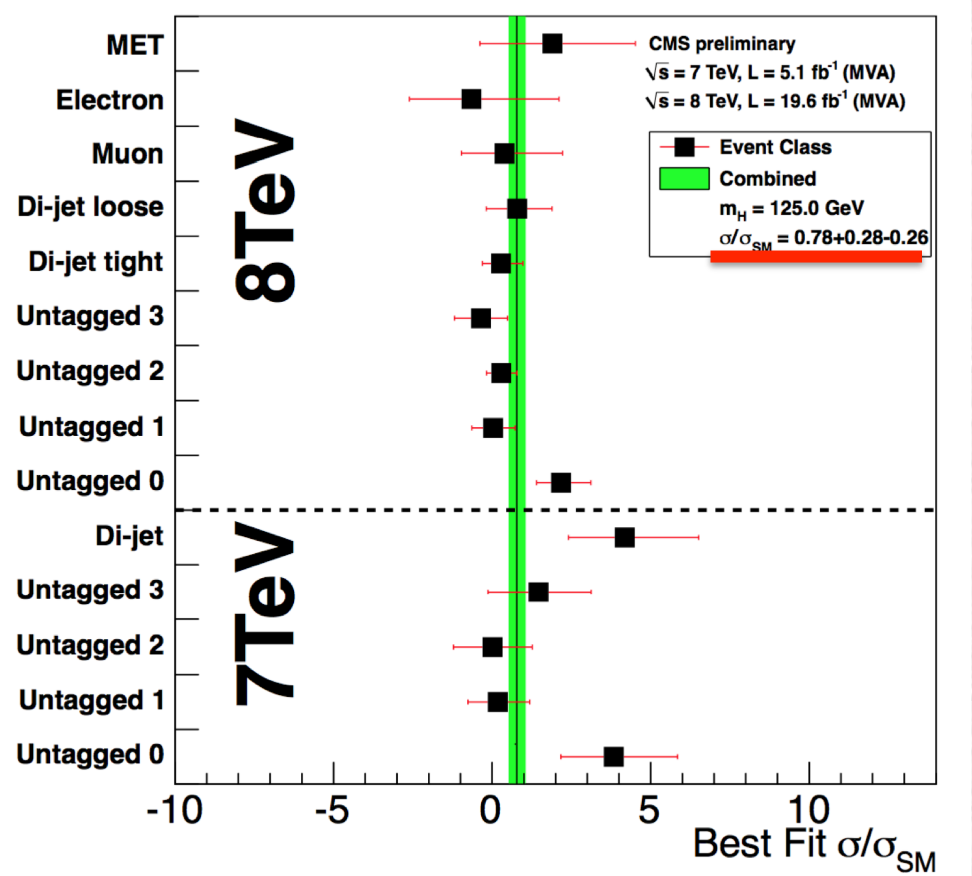
$$(gg \to H \to \gamma\gamma)_{GHU}/(gg \to H \to \gamma\gamma)_{SM}$$



Diphoton decay data



$$\sigma/\sigma_{SM} = 1.57 \pm 0.22(\mathrm{stat}) + 0.24 - 0.18(\mathrm{syst})$$



Extension is required

Two extensions

1:Color Singlet Fermions

&

2:Colored Fermions

Why fermions??

∵ KK fermion contributions to

$(H\rightarrow\gamma\gamma)_{KK\ fermions}/(H\rightarrow\gamma\gamma)_{SM} > 0$

	$gg \to H$	$H \to \gamma\gamma$
Top	$\frac{\alpha_s}{12\pi v}$	$\frac{2\alpha_{em}}{9\pi v}$
W		$-\frac{7\alpha_{em}}{8\pi v}$
KK Top	$-\frac{\alpha_s}{12\pi v}\frac{1}{3}(\pi m_t R)^2$	$-\frac{2\alpha_{em}}{9\pi v}\frac{1}{3}(\pi m_t R)^2$
KK W		$\frac{7\alpha_{em}}{8\pi v}\frac{1}{3}(\pi m_W R)^2$
GHU/SM	$1-\frac{1}{3}(\pi m_t R)^2$	$1+\frac{1}{141}(\pi m_W R)^2$

Negative (Top and W contributions to $H \to \gamma\gamma$)

KK mode contributions: opposite sign!!

Color Singlet Fermions

"Diphoton Decay Excess and 125 GeV Higgs Boson in Gauge-Higgs Unification"
NM and Nobuchika Okada
PRD87 095019 (2013)

Simplest extension:

"Extra Leptons"

(colored particles greatly affect gg->H, but discuss later)

Two examples:

10, 15 reps. of SU(3) with bulk mass

& half-periodic BC $\psi(y+2\pi R) = -\psi(y)$

No unwanted massless fermions

1st KK mass = 1/(2R)

⇒ Higgs mass enhancement

Helpful to adjust 125 GeV Higgs

Diphoton decay from 10 & 15

$$C_{\gamma\gamma}^{KKlepton10} = (Q-1)^2 F(3m_W) + (Q-1)^2 F(m_W) + Q^2 F(2m_W) + (Q+1)^2 F(m_W)$$

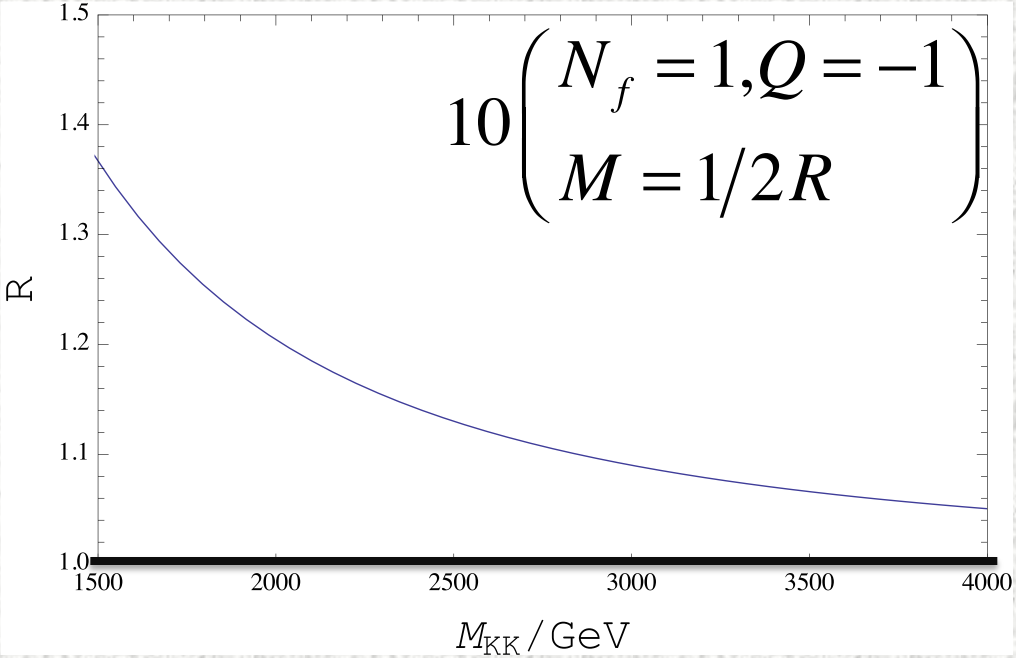
$$C_{\gamma\gamma}^{KKlepton15} = (Q-4/3)^2 F(4m_W) + (Q-4/3)^2 F(2m_W) + (Q-1/3)^2 F(3m_W)$$
$$+ (Q-1/3)^2 F(m_W) + (Q+2/3)^2 F(2m_W) + (Q+5/3)^2 F(m_W)$$

Q: U(1)' charge

$$F(m_W) = \frac{\alpha_{em}}{6\pi v} N_f m_W \sum_{n=0}^{\infty} \left[\frac{\frac{n+1/2}{R} + m_W}{M^2 + \left(\frac{n+1/2}{R} + m_W\right)^2} - \frac{\frac{n+1/2}{R} - m_W}{M^2 + \left(\frac{n+1/2}{R} - m_W\right)^2} \right]$$

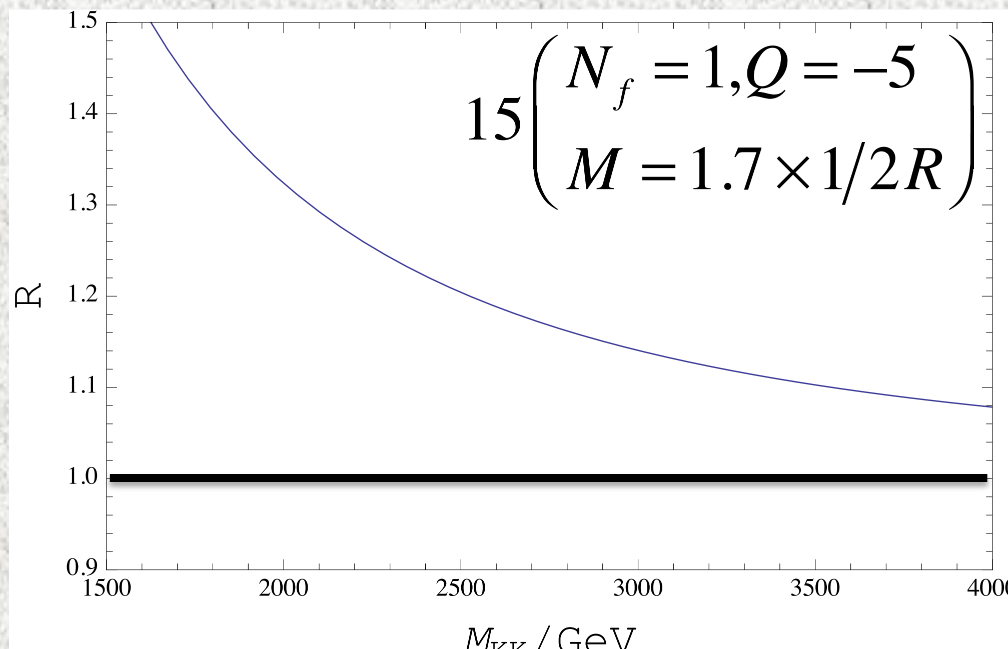
$$\cong -\frac{\alpha_{em}}{3\pi v} N_f m_W^2 \sum_{n=0}^{\infty} \frac{\left(\frac{n+1/2}{R}\right)^2 - M^2}{\left[\left(\frac{n+1/2}{R}\right)^2 + M^2\right]^2} \left(m_W^2 \ll m_n^2\right) = -\frac{\alpha_{em}}{6\pi v} N_f \frac{(\pi m_W R)^2}{\cosh(\pi M R)}$$

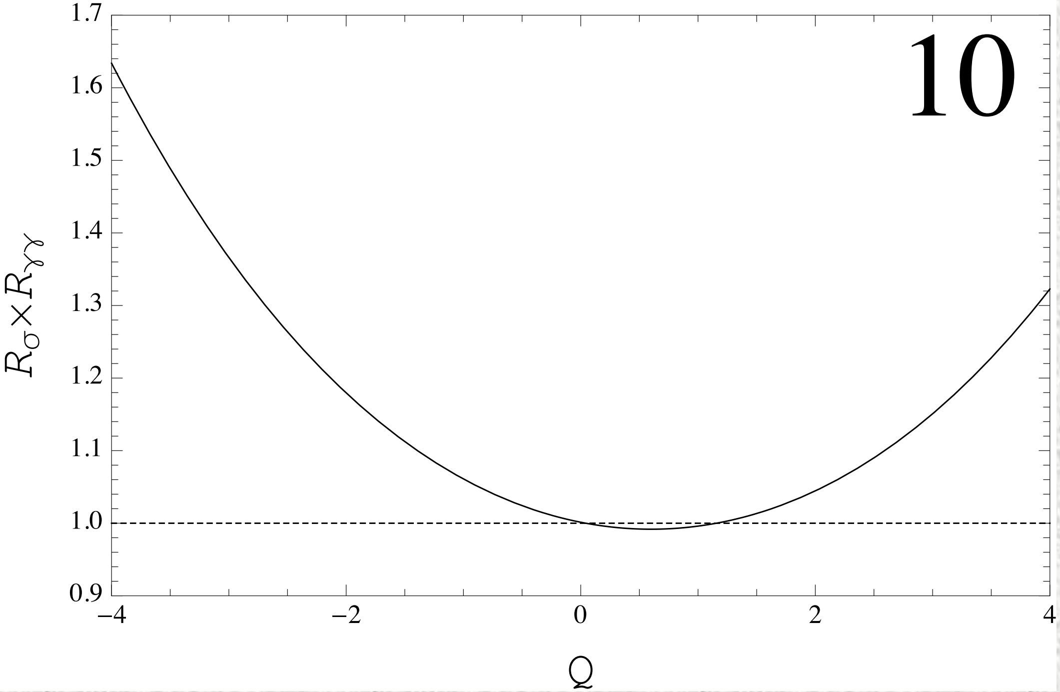
Negative



$$R = \frac{\sigma(gg \to H)_{GHU+10} \times BR(H \to \gamma\gamma)_{GHU+10}}{\sigma(gg \to H)_{SM} \times BR(H \to \gamma\gamma)_{SM}}$$

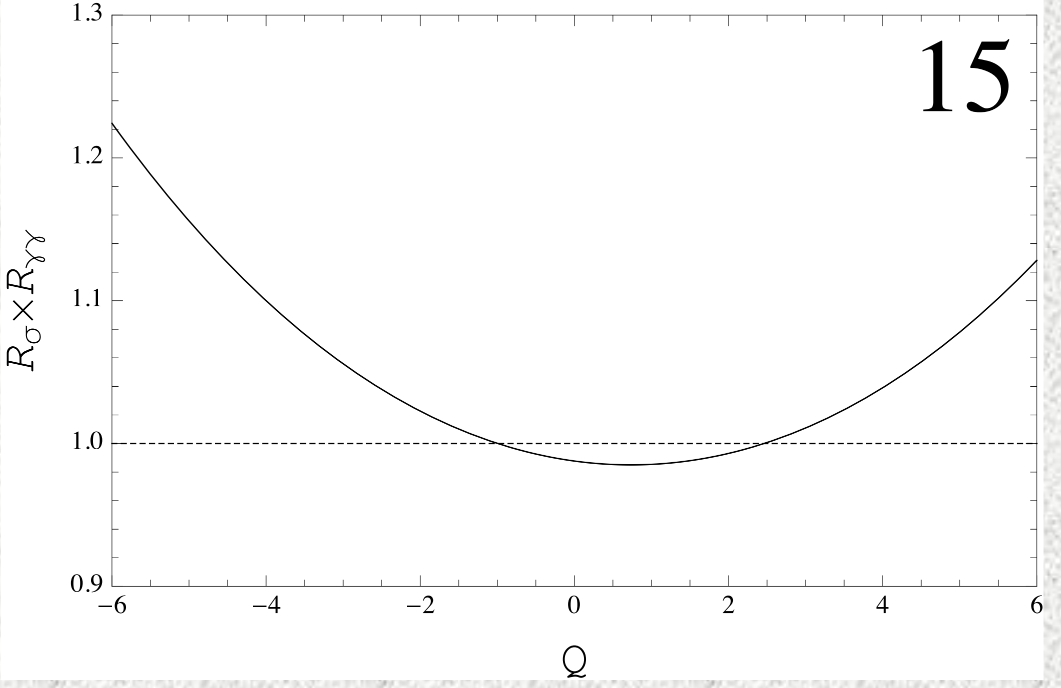
$$R = \frac{\sigma(gg \to H)_{GHU+15} \times BR(H \to \gamma\gamma)_{GHU+15}}{\sigma(gg \to H)_{SM} \times BR(H \to \gamma\gamma)_{SM}}$$





$$R = \frac{\sigma(gg \to H)_{GHU} \times BR(H \to \gamma\gamma)_{GHU}}{\sigma(gg \to H)_{SM} \times BR(H \to \gamma\gamma)_{SM}}$$

1/R = 3TeV fixed



Higgs mass analysis

Higgs mass analysis by 4D EFT approach

In GHU, m_H likely to be small ∵ loop generated

Instead of 5D Higgs potential minimization,

solve 1-loop RGE for Higgs quartic coupling λ
by imposing BC $\lambda=0$@$1/R$ "gauge-Higgs condition"

Haba, Matsumoto, Okada & Yamashita (2006, 2008)

Natural realization of GHU in 4D viewpoint:
$V_H = 0$ above $1/R$ by 5D gauge invariance

Furthermore, NO vacuum instability

This approach greatly simplifies Higgs mass study

1-loop RGE for λ

$$\frac{d\lambda}{d\ln\mu}=\frac{1}{16\pi^2}\left[12\lambda^2-\left(\frac{9}{5}g_1^2+9g_2^2\right)\lambda+\frac{9}{4}\left(\frac{3}{25}g_1^4+\frac{2}{5}g_1^2g_2^2+g_2^4\right)+4\left(3y_t^2+N_fC_q(R)\left(\sqrt{2}g_2\right)^2\right)\lambda-4\left(3y_t^4+N_fC_f(R)\left(\sqrt{2}g_2\right)^4\right)\right](\mu\geq M)$$

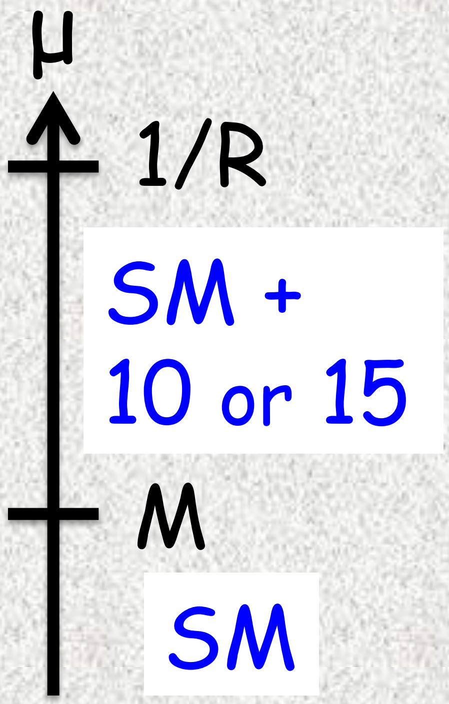
$$\frac{d\lambda}{d\ln\mu}=\frac{1}{16\pi^2}\left[12\lambda^2-\left(\frac{9}{5}g_1^2+9g_2^2\right)\lambda+\frac{9}{4}\left(\frac{3}{25}g_1^4+\frac{2}{5}g_1^2g_2^2+g_2^4\right)+12y_t^2\lambda-12y_t^4\right](\mu<M)$$

$$C_f(10)=2\left[(3/2)^4+(1/2)^4+1^4+(1/2)^4\right]$$

$$C_q(10)=2\left[(3/2)^2+(1/2)^2+1^2+(1/2)^2\right]$$

$$C_f(15)=2\left[2^4+1^4+(3/2)^4+(1/2)^4+1^4+(1/2)^4\right]$$

$$C_q(15)=2\left[2^2+1^2+(3/2)^2+(1/2)^2+1^2+(1/2)^2\right]$$



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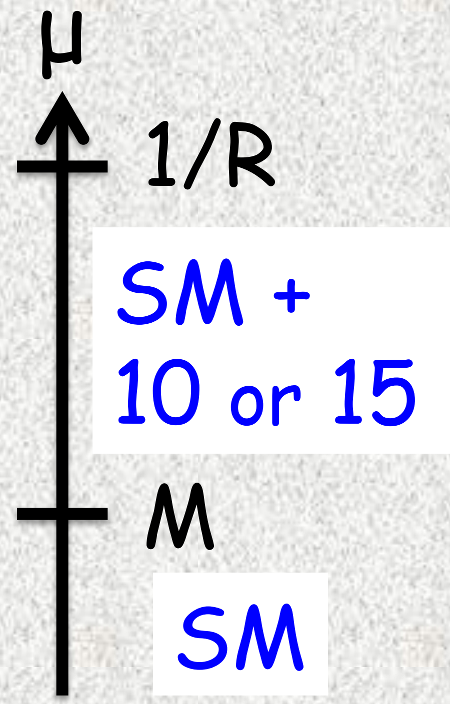
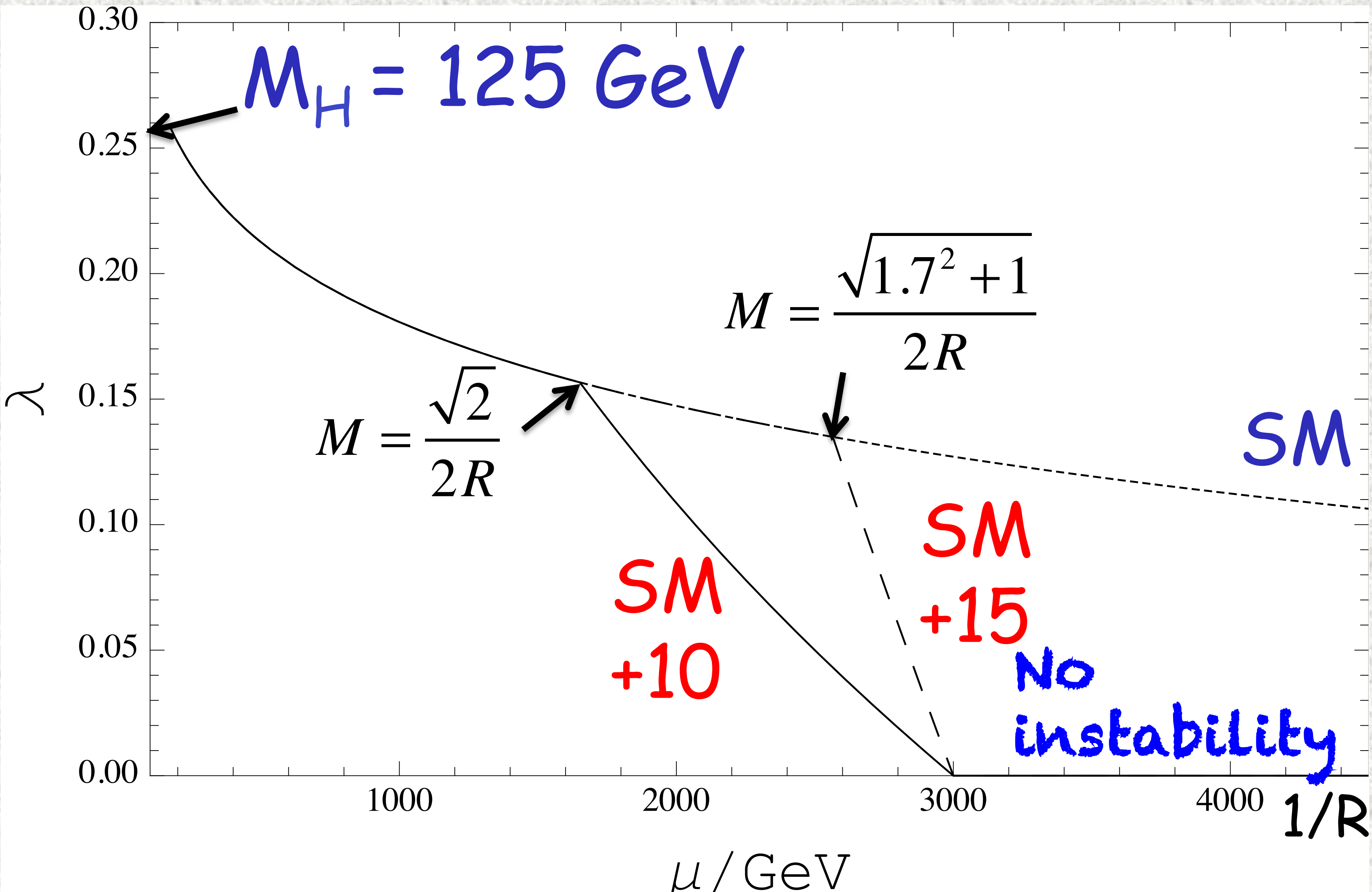
- Contributions from 1st KK mode with mass 1/(2R) in 10 or 15 rep.
- 2nd term $\propto (\sqrt{2}g_2)^4$ dominated
- Negative sign



Numerical results for 1-loop RGE of λ



TeV Scale Colored Fermions

"125 GeV Higgs Boson & TeV Scale Colored Fermion in Gauge-Higgs Unification"

NM and Nobuchika Okada

arXiv: 1310.3348

Another possibility to realize 125 GeV Higgs mass by introducing extra colored fermions

Colored fermions contribute to $gg \to H$ destructively

⇒ LHC Data put a lower bound for KK masses

⇒ It would be interesting
if the lower bound is within a detectable range
w/o contradicting 125 GeV Higgs mass

Result:

M_{KK}=2-3TeV for $\sigma(gg \to H)/\sigma_{SM} \sim 0.9\text{-}0.95$

Extra colored fermions have half-periodic BC

⇒ the lightest KK particle (LKP) is stable,
but stable colored particle is
cosmologically disfavor

⇒ introduce the mixing btw the LKP & SM quarks
on the brane for decay to SM quarks

⇒ U(1)' charge fixed to be
-1/3 (2/3) for down(up)-type quarks

⇒ Q=2/3, 5/3 for **10**-plet, Q=1, 2 for **15**-plet
(Q-1=-1/3, 2/3 for 10, Q-4/3=-1/3 or 2/3)

Mass eigenvalues & charges of 10 & 15

$$10 = 1_{-1} + 2_{-1/2} + 3_0 + 4_{1/2}$$

U(1) charge of SU(2)xU(1)

"elemag charge" of SU(2)xU(1)

$$\left(m_{n,-1}^{(\pm)}\right)^2 = \left(m_{n+1/2}^{(\pm)} \pm 3m_W\right)^2 + M^2, \left(m_{n+1/2}^{(\pm)} \pm m_W\right)^2 + M^2$$

$$\left(m_{n,0}^{(\pm)}\right)^2 = \left(m_{n+1/2}^{(\pm)} \pm 2m_W\right)^2 + M^2, m_{n+1/2}^2 + M^2$$

$$\left(m_{n,+1}^{(\pm)}\right)^2 = \left(m_{n+1/2}^{(\pm)} \pm m_W\right)^2 + M^2, \left(m_{n,+2}^{(\pm)}\right)^2 = m_{n+1/2}^2 + M^2$$

$$15 = 1_{-4/3} + 2_{-5/6} + 3_{-1/3} + 4_{1/6} + 5_{2/3}$$

$$\left(m_{n,-4/3}^{(\pm)}\right)^2 = \left(m_{n+1/2}^{(\pm)} \pm 4m_W\right)^2 + M^2, \left(m_{n+1/2}^{(\pm)} \pm 2m_W\right)^2 + M^2, m_{n+1/2}^2 + M^2$$

$$\left(m_{n,-1/3}^{(\pm)}\right)^2 = \left(m_{n+1/2}^{(\pm)} \pm 3m_W\right)^2 + M^2, \left(m_{n+1/2}^{(\pm)} \pm m_W\right)^2 + M^2$$

$$\left(m_{n,2/3}^{(\pm)}\right)^2 = \left(m_{n+1/2}^{(\pm)} \pm 2m_W\right)^2 + M^2, m_{n+1/2}^2 + M^2$$

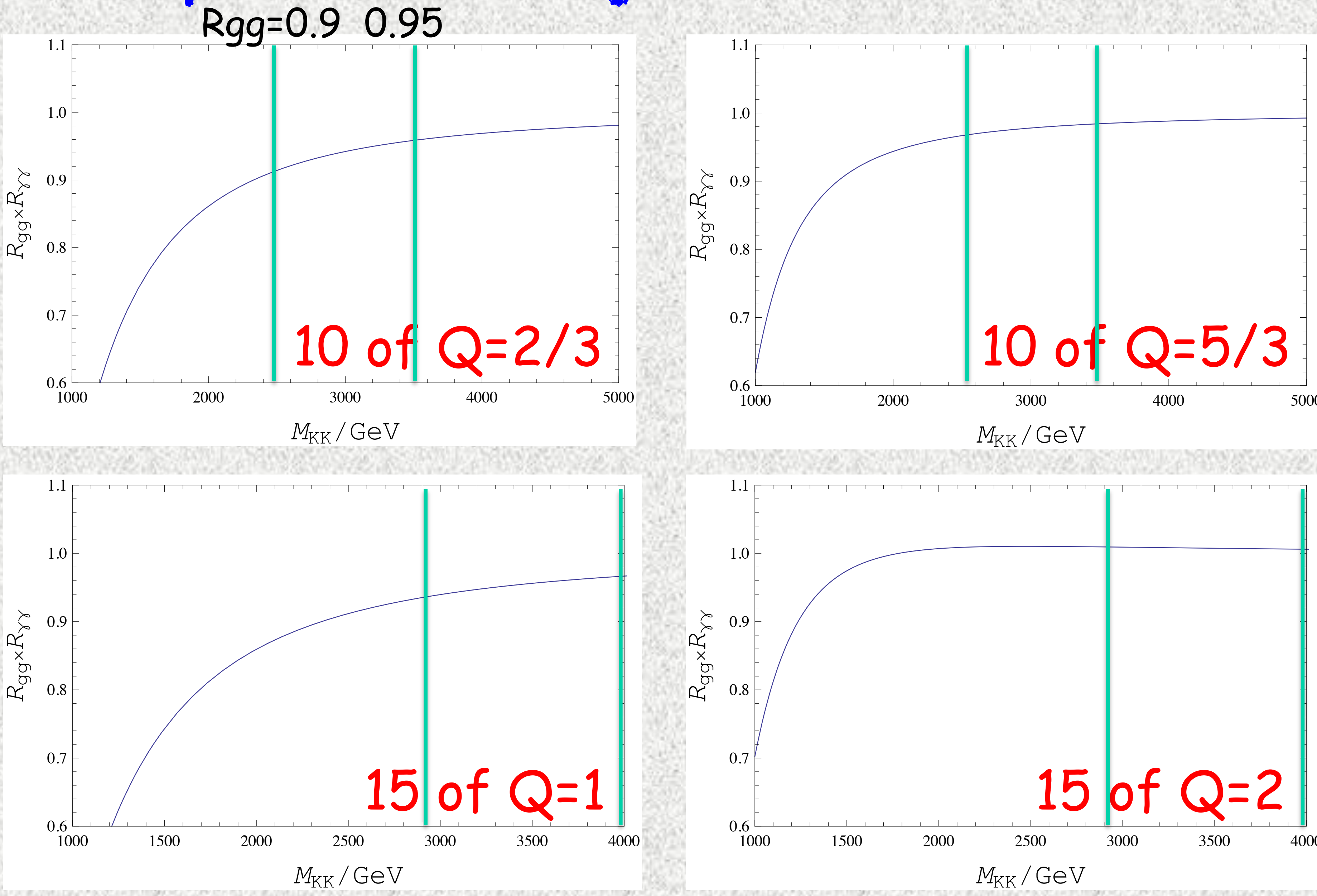
$$\left(m_{n,5/3}^{(\pm)}\right)^2 = \left(m_{n+1/2}^{(\pm)} \pm m_W\right)^2 + M^2, \left(m_{n,8/3}^{(\pm)}\right)^2 = m_{n+1/2}^2 + M^2$$

Lower bound on KK scale etc from gluon fusion

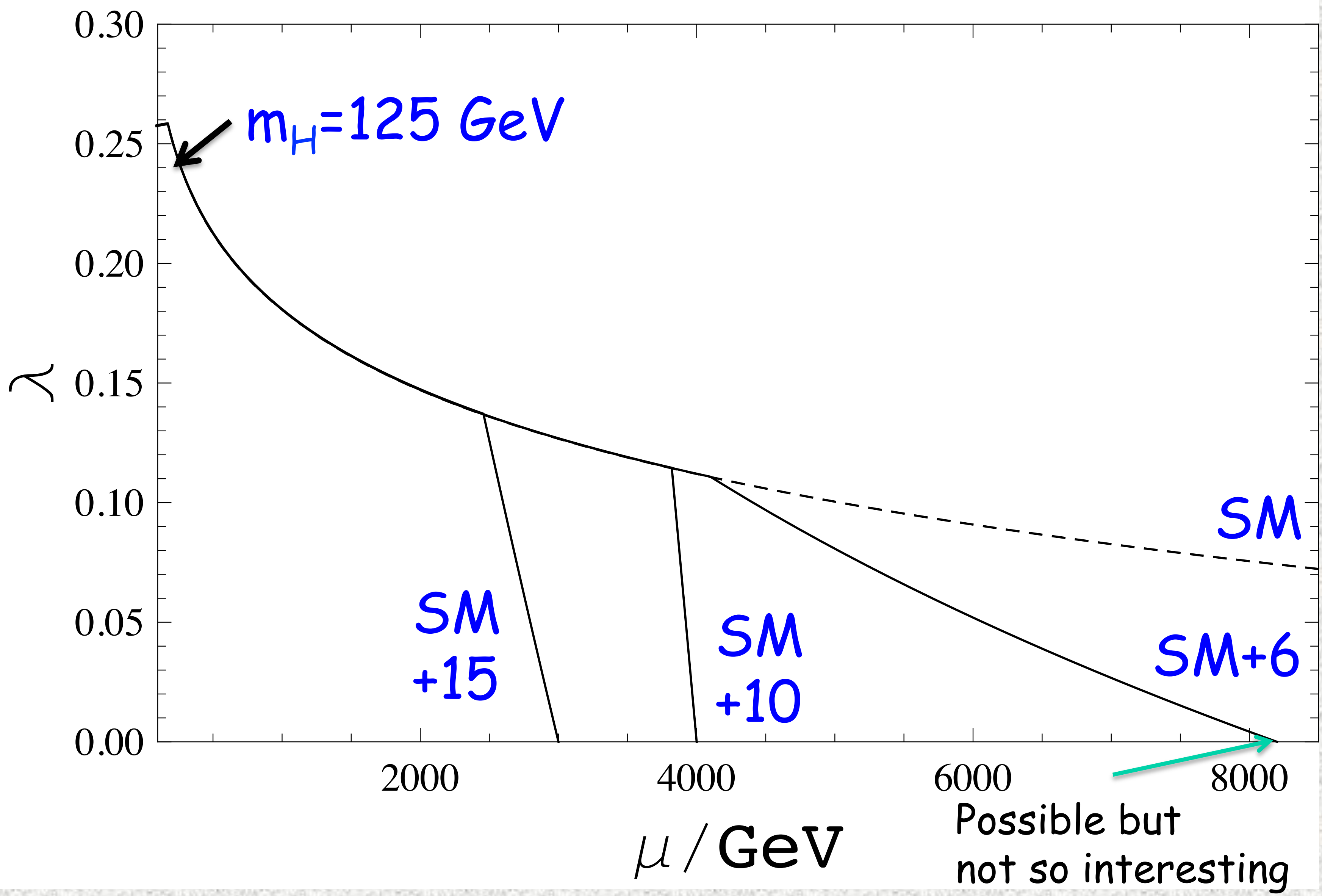
10-plet	$R_{gg} = 0.9$	$R_{gg} = 0.95$
$M_{\rm KK}$ (TeV)	2.54	3.45
$m_0^{(\pm)}$ (TeV)	2.05	2.91
$m_{\rm lightest}$ (TeV)	1.91	2.77

15-plet	$R_{gg} = 0.9$	$R_{gg} = 0.95$
$M_{\rm KK}$ (TeV)	2.88	4.05
$m_0^{(\pm)}$ (TeV)	2.73	3.87
$m_{\rm lightest}$ (TeV)	2.57	3.71

Diphoton Decay Signal Strength



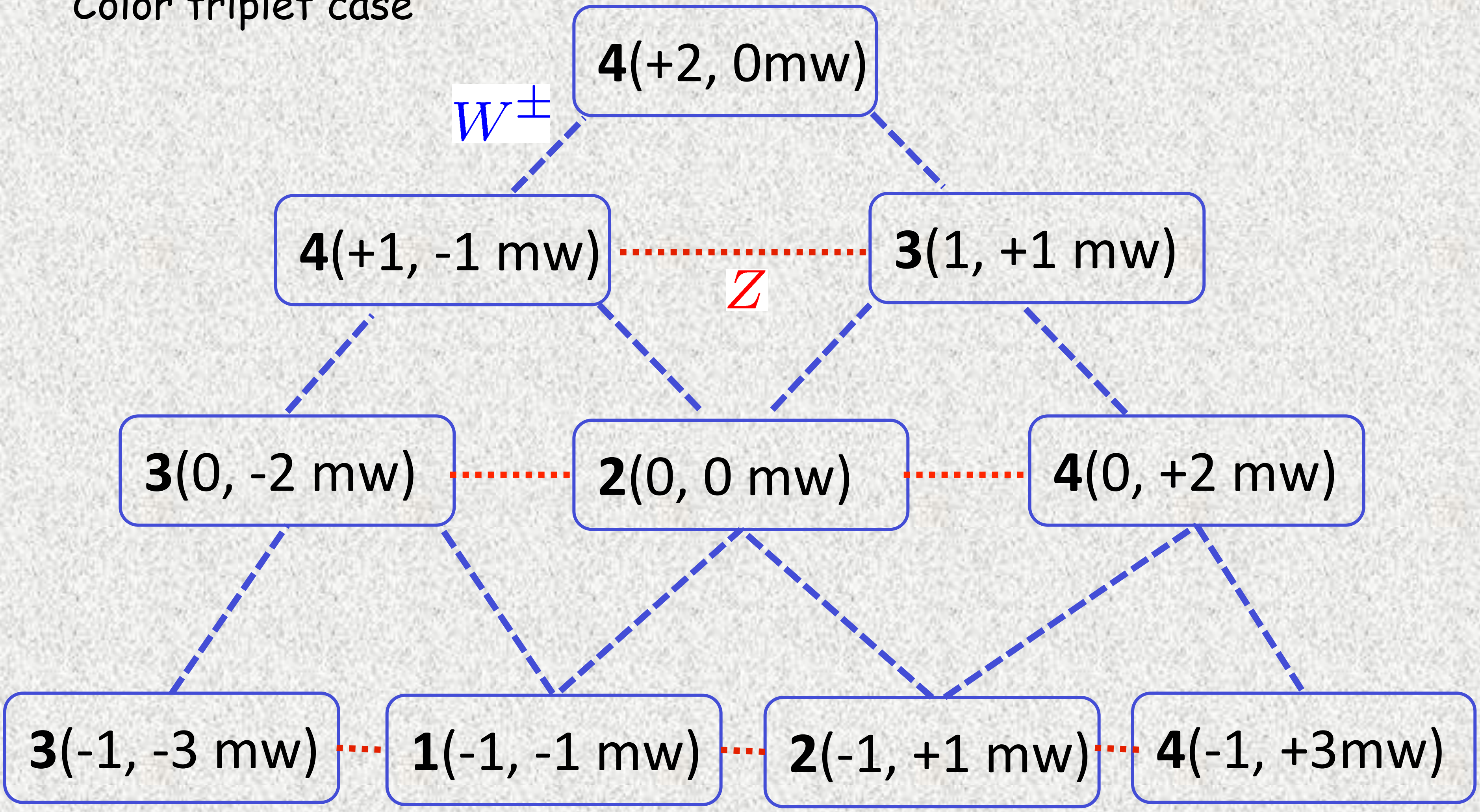
1-loop RGE for Higgs quartic coupling



Interactions between KK modes & W, Z

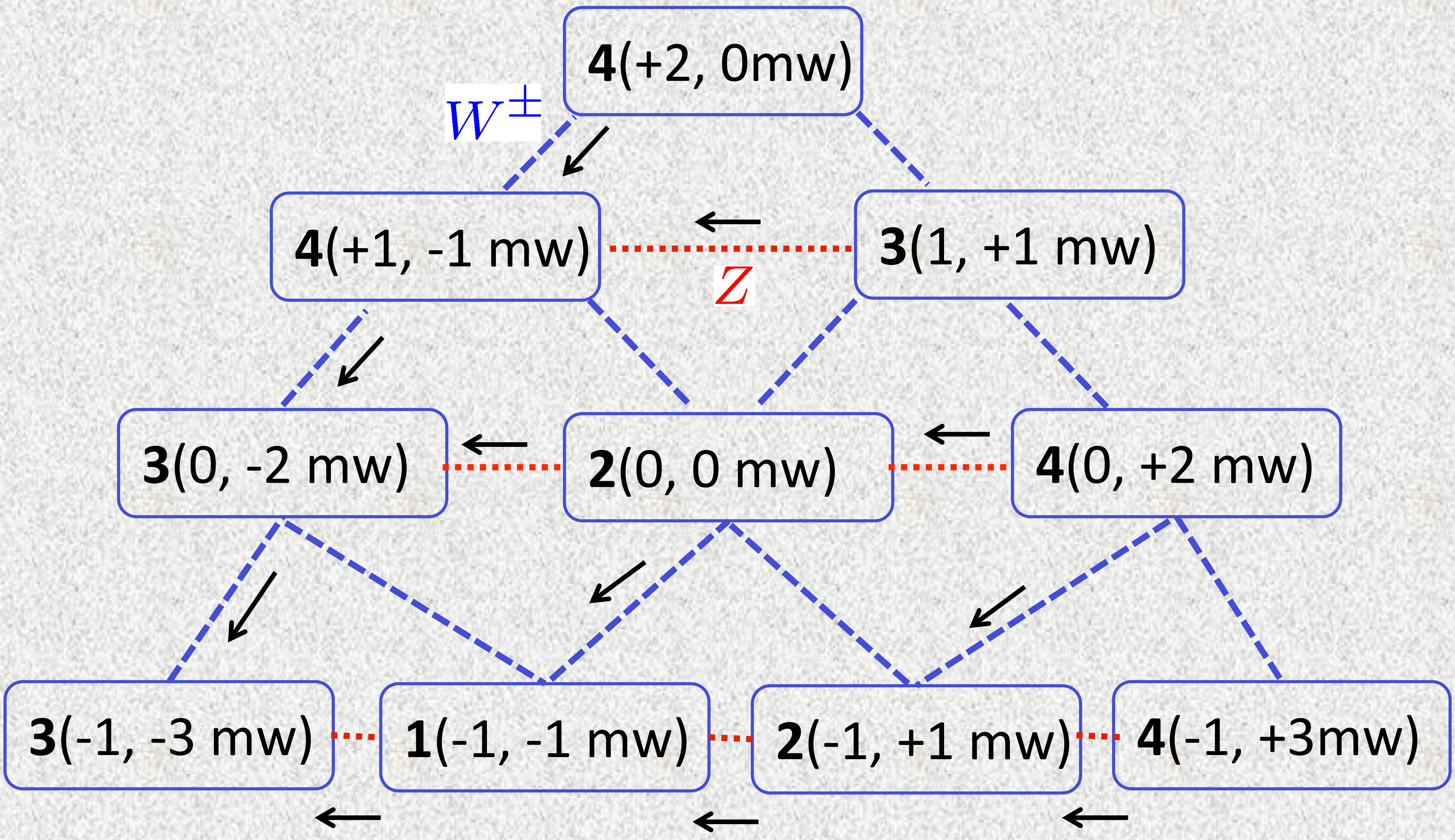
Ex: 10-plet: $10 = 1_{-1} \oplus 2_{-1/2} \oplus 3_0 \oplus 4_{1/2}$

Color triplet case



Heavy fermion cascades

Ex: 10-plet: $10 = 1_{-1} \oplus 2_{-1/2} \oplus 3_0 \oplus 4_{1/2}$



$H \to Z\gamma$

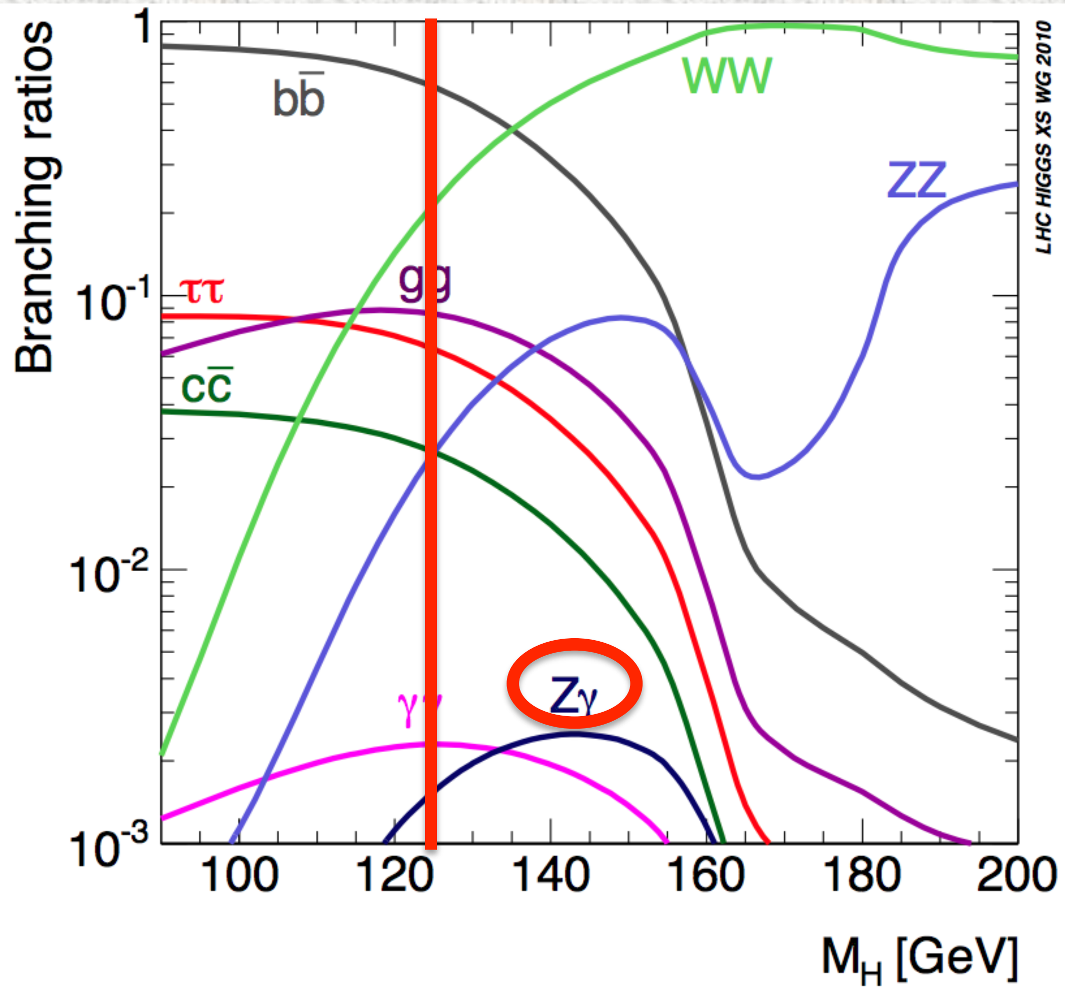
"H to Z Gamma in Gauge-Higgs Unification"

NM & Nobuchika Okada,

PRD88 (2013) 037701

A Comment on H→Zγ

NM & N.Okada, PRD88 037701 (2013)



KK modes have EW charges

↓

Naturally, a deviation of Zγ decay from the SM prediction expected

Model dep.

Correlation btw γγ & Zγ is interesting

No KK mode contributions to Zγ decay@1-loop

Simple reason: in the mass eigenstates, H and γ couples to KK modes with same mass eigenstates, but Z does not

Fermion coupling

$$\left(\bar{\psi}_0^{(n)},\bar{\psi}_+^{(n)},\bar{\psi}_-^{(n)}\right)\begin{pmatrix} 2\gamma_\mu/\sqrt{3} & W_\mu^+ & W_\mu^+ \\ W_\mu^- & -\gamma_\mu/\sqrt{3} & -Z_\mu \\ W_\mu^- & -Z_\mu & -\gamma_\mu/\sqrt{3} \end{pmatrix}\gamma^\mu\begin{pmatrix}\psi_0^{(n)} \\ \psi_+^{(n)} \\ \psi_-^{(n)}\end{pmatrix}, \psi_{0,\pm}^{(n)} : \frac{n}{R}, \frac{n}{R} \pm m_f$$

ZW^nW^n coupling

$$Z_\mu\left(W_{\mu\nu+}^{\mp(n)}, W_{\mu\nu-}^{\mp(n)}\right)\begin{pmatrix} 0 & \mp i \\ \pm i & 0 \end{pmatrix}\left(W_{\nu+}^{\pm(n)}, W_{\nu-}^{\pm(n)}\right)$$

$$W_{\mu\pm}^{(n)} : n/R \pm m_W, W_{\mu\nu} \equiv \partial_\mu W_\nu - \partial_\nu W_\mu$$

$Z\gamma W^nW^n$ coupling

$$Z^\mu\gamma_\nu\left(W_{\mu+}^{\mp(n)}, W_{\mu-}^{\mp(n)}\right)\begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix}\begin{pmatrix} W_+^{\pm\nu(n)} \\ W_-^{\pm\nu(n)} \end{pmatrix} + 2Z_\mu\gamma^\mu\left(W_{\nu+}^{\mp(n)}, W_{\nu-}^{\mp(n)}\right)\begin{pmatrix} 0 & i \\ -i & 0 \end{pmatrix}\begin{pmatrix} W_+^{\pm\nu(n)} \\ W_-^{\pm\nu(n)} \end{pmatrix}$$

No H-Z-γ coupling@1-loop found

Summary

- We have calculated KK mode contributions to
  $gg \to H$ & $H \to \gamma\gamma$ @LHC in 5D SU(3)xU(1)′ GHU
- Simplest model cannot explain the data
- Extra fermions can enhance $H \to \gamma\gamma$ as we like
  by adjusting U(1)′ charges

  ex. Color singlet & Colored fermions
  in 10 & 15 reps. of SU(3) w/ bulk mass
  & half-periodic BC
- These fermions also help to enhance Higgs mass

Summary

- 1-loop RGE analysis of Higgs quartic coupling with GH condition $\lambda=0@M_{KK}$

  ⇒ No instability

- Extra fermions are (some kind of) Z_2 odd & stable due to the half-periodic BC

  (i) Color singlet case ⇒ LKP can be DM candidate in case of vanishing electric charge (10: 2TeV, 15: 3TeV)

  (ii) Colored case ⇒ TeV scale LKP decay to the SM quark by the mixing