Higgs-Dilaton mixing using the modified dilaton couplings to the SM fields

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Based on the work in progress with Prof. P. Ko, KIAS.

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Introduction

- **At last, we have Higgs boson with 125 GeV — ?**
- **Its properties are waiting to be revealed, SM or not?**
- **Still, the data seem to be consistent with the SM...really?**

  $\rightarrow$ **Di-Photon enhancement?**

  $\rightarrow$ $\tau\bar{\tau}$ **mode?**

Introduction

- **Alternatives to the SM?**
- **Dilaton as a Higgs imposter :**

  $\rightarrow$ Many models, depending on the hidden conformal sectors.

  $\rightarrow$ Technidilaton, composite Higgs, etc. (Talks by Michio Hashimoto, Toshifumi Yamada, and Stefano Moretti.)

  $\rightarrow$ Radion models from RS, same forms.

- **Dilaton-Higgs mixing?**

Dilaton couplings to the SM fields

- **Usual assumption on dilaton couplings to the SM,**

$$\mathcal{L}_{\rm int} = \frac{\chi}{f_\chi}\; T^\mu_\mu$$
$$= \frac{\chi}{f_\chi}\left[\mu_H^2 H^\dagger H + m_W^2 W^+ W^- + m_Z^2 Z_\mu Z^\mu + \sum_f m_f \bar{f} f + \frac{\beta_G}{g_G} G_{\mu\nu} G^{\mu\nu}\right]$$

- **Similar to the SM, except for f_χ instead of v.**
- **All–assuming the dilaton coupling to the EW sector "AFTER" EWSB.** $\rightarrow$ **Classically, Higgs mass parameter is the only scaling-violating term in the SM Lagrangian.**
- **Proposal :** $T^\mu_\mu \propto \mu^2 H^\dagger H$ **+ Scale Anomaly.**

Higgs+Dilaton

- **Higgs can be lighter that scale symmetry breaking scale or dilaton**
- **Dilaton only couples to Higgs mass paramter...+ scale anomaly.**
- **In terms of $\chi \equiv \mathrm{e}^{\phi/f_\phi}$, the Lagrangian for SM + dilaton can be written as**

$$
\begin{aligned}
\mathcal{L} = \quad & \mathcal{L}_{\mathrm{SM}}(\mu^2 = 0) + \frac{f_\phi^2}{2}\partial_\mu \chi \partial^\mu \chi \\
+ \quad & \mu^2 \chi^2 H^\dagger H \\
+ \quad & \log\left(\frac{\chi}{S(x)}\right)\left\{\frac{\beta_{g_1}(g_1)}{2g_1} B_{\mu\nu}B^{\mu\nu} + \frac{\beta_{g_2}(g_2)}{2g_2} W^i_{\mu\nu}W^{i\mu\nu} + \frac{\beta_{g_3}(g_3)}{2g_3} G^a_{\mu\nu}G^{a\mu\nu}\right\} \\
- \quad & \log\left(\frac{\chi}{S(x)}\right)\left\{\beta_u\left(\mathbf{Y_u}\right)\bar{Q}_L\tilde{H}u_R + \beta_d\left(\mathbf{Y_u}\right)\bar{Q}_L H d_R + \beta_l\left(\mathbf{Y_u}\right)\bar{l}_L H e_R + H.c.\right\} \\
- \quad & \log\left(\frac{\chi}{S(x)}\right)\frac{\beta_\lambda(\lambda)}{4}\left(HH^\dagger\right)^2 \\
- \quad & \frac{f_\phi^2 m_\phi^2}{4}\chi^4\left\{\log\chi - \frac{1}{4}\right\}.
\end{aligned}
$$

Potential Analysis

- **Minimizing the extended potential generally gives**

$$\langle H\rangle = (0, v/\sqrt{2})^T, \quad \langle\phi\rangle = \bar{\phi}.$$

- **From tadpole condition for Higgs boson and dilaton,**

$$\begin{aligned} \lambda v^2 &= \mu^2 \mathrm{e}^{2\frac{\bar{\phi}}{f_\phi}}, \\ \mu^2 v^2 &= f_\phi m_\phi^2 \bar{\phi}\ \mathrm{e}^{2\frac{\bar{\phi}}{f_\phi}}. \end{aligned}$$

- **Similar to the singlet extended SM, but the structures are different.**

Mass Formula

- **The Higgs-Dilaton mass matrix becomes**

$$\mathcal{M}^2(h,\phi) = \begin{pmatrix} m^2_{hh} & m^2_{h\phi} \\ m^2_{\phi h} & m^2_{\phi\phi} \end{pmatrix} = \begin{pmatrix} 2\lambda v^2 & -2\frac{\lambda v^3}{f_\phi} e^{-2\frac{\bar\phi}{f_\phi}} \\ -2\frac{\lambda v^3}{f_\phi} e^{-2\frac{\bar\phi}{f_\phi}} & m^2_\phi e^{2\frac{\bar\phi}{f_\phi}}\left(1+2\frac{\bar\phi}{f_\phi}\right) \end{pmatrix} \equiv \begin{pmatrix} m^2_h & -m^2_h \frac{v}{f_\phi} e^{-2\frac{\bar\phi}{f_\phi}} \\ -m^2_h \frac{v}{f_\phi} e^{-2\frac{\bar\phi}{f_\phi}} & \tilde m^2_\phi e^{2\frac{\bar\phi}{f_\phi}} \end{pmatrix}$$

where

$$\tilde m^2_\phi = m^2_\phi \left(1 + 2\frac{\bar\phi}{f_\phi}\right).$$

- **Mass eigenvalues and mixing angle :**

$$m^2_{H_{1,2}} = \frac{m^2_h + \tilde m^2_\phi e^{2\frac{\bar\phi}{f_\phi}} \mp \sqrt{\left(m^2_h - \tilde m^2_\phi e^{2\frac{\bar\phi}{f_\phi}}\right)^2 + 4e^{-4\frac{\bar\phi}{f_\phi}} \frac{v^2}{f^2_\phi} m^4_h}}{2}$$

with

$$\tan\alpha = \frac{-m^2_h \frac{v}{f_\phi} e^{-2\frac{\bar\phi}{f_\phi}}}{\tilde m^2_\phi e^{\frac{2\bar\phi}{f_\phi}} - m^2_{H_1}}.$$

$$\mathcal{L}(f,\bar{f},H_{i=1,2}) = -\frac{m_f}{v}\bar{f}fh = -\frac{m_f}{v}\bar{f}f(H_1 c_\alpha + H_2 s_\alpha) \quad cf. \quad -\frac{v}{f_\phi}\frac{\beta_f}{y_f}\frac{m_f}{v}\bar{f}f\phi\, e^{-\bar{\phi}/f_\phi}$$

$$\mathcal{L}(g,g,H_{i=1,2}) = \frac{e^{-\bar{\phi}/f_\phi}}{f_\phi}\frac{\beta_3(g_3)}{2g_3}G_{\mu\nu}G^{\mu\nu}\phi = \frac{e^{-\bar{\phi}/f_\phi}}{f_\phi}\frac{\beta_3(g_3)}{2g_3}G_{\mu\nu}G^{\mu\nu}(-H_1 s_\alpha + H_2 c_\alpha)$$

$$\mathcal{L}(W,W,H_{i=1,2}) = \frac{2m_W^2}{v}W_\mu^+ W^{-\mu}h + \frac{e^{-\bar{\phi}/f_\phi}}{f_\phi}\frac{\beta_2(g_2)}{2g_2}W_{\mu\nu}W^{\mu\nu}\phi$$

$$= \frac{2m_W^2}{v}W_\mu^+ W^{-\mu}(H_1 c_\alpha + H_2 s_\alpha) + \frac{e^{-\bar{\phi}/f_\phi}}{f_\phi}\frac{\beta_2(g_2)}{2g_2}W_{\mu\nu}W^{\mu\nu}(-H_1 s_\alpha + H_2 c_\alpha)$$

$$\mathcal{L}(Z,Z,H_{i=1,2}) = \frac{m_Z^2}{v}Z_\mu Z^\mu h + \frac{e^{-\bar{\phi}/f_\phi}}{f_\phi}\left\{c_W^2\frac{\beta_2(g_2)}{2g_2} + s_W^2\frac{\beta_1(g_1)}{2g_1}\right\}Z_{\mu\nu}Z^{\mu\nu}\phi$$

$$= \frac{m_Z^2}{v}Z_\mu Z^\mu(H_1 c_\alpha + H_2 s_\alpha) + \frac{e^{-\bar{\phi}/f_\phi}}{f_\phi}\left\{c_W^2\frac{\beta_2(g_2)}{2g_2} + s_W^2\frac{\beta_1(g_1)}{2g_1}\right\}Z_{\mu\nu}Z^{\mu\nu}(-H_1 s_\alpha + H_2 c_\alpha)$$

$$\mathcal{L}(\gamma,\gamma,H_{i=1,2}) = \frac{e^{-\bar{\phi}/f_\phi}}{f_\phi}\left\{s_W^2\frac{\beta_2(g_2)}{2g_2} + c_W^2\frac{\beta_1(g_1)}{2g_1}\right\}F_{\mu\nu}F^{\mu\nu}\phi$$

$$= \frac{e^{-\bar{\phi}/f_\phi}}{f_\phi}\left\{s_W^2\frac{\beta_2(g_2)}{2g_2} + c_W^2\frac{\beta_1(g_1)}{2g_1}\right\}F_{\mu\nu}F^{\mu\nu}(-H_1 s_\alpha + H_2 c_\alpha)$$

$$\mathcal{L}(\gamma,Z,H_{i=1,2}) = \frac{e^{-\bar{\phi}/f_\phi}}{f_\phi}2s_W c_W\left\{\frac{\beta_2(g_2)}{2g_2} - \frac{\beta_1(g_1)}{2g_1}\right\}Z_{\mu\nu}F^{\mu\nu}\phi$$

$$= \frac{e^{-\bar{\phi}/f_\phi}}{f_\phi}2s_W c_W\left\{\frac{\beta_2(g_2)}{2g_2} - \frac{\beta_1(g_1)}{2g_1}\right\}Z_{\mu\nu}F^{\mu\nu}(-H_1 s_\alpha + H_2 c_\alpha)$$

Numerical Results

- **Inputs :** f_ϕ **and** m_ϕ **(**$m_h = 125$**GeV,** α **and** m_H **are calculated.)**

Decay	Production	r_i
$WW*$	ggF	**ATLAS 158 : [0.9, 2.1]** **CMS 045 : [0.5, 1.1]**
	VBF	**ATLAS : [-]** **CMS 045 : [0.5, 1.1]**
	VH	**ATLAS 092 : [-]** **CMS 045 : [-2.3,2]**
$ZZ*$	ggF	**ATLAS 169 : [0.9, 1.7]** **CMS 045 : [0.5,1.1]**
$\gamma\gamma$	ggF	**ATLAS 168 : [1.38, 2.17]** **CMS 045 : [0.9, 2]**
	VBF	**ATLAS 091 : [1.4, 4]** **CMS 045 : [1.2, 3.5]**
$b\bar{b}$	VH	**ATLAS 161 : [, 18]** **CMS 045 : [0.7, 2]**
	$t\bar{t}H$	**ATLAS 135 : [, 13.1]** **CMS 045 : [-2.6, 1.4]**
$\tau\bar{\tau}$	ggF	**ATLAS 160 : [-1.1, 5.8]** **CMS 045 : [0.1, 1.6]**
	VBF	**ATLAS 160 : [-1.1, 2.6]** **CMS 045 : [0, 1.7]**
	VH	**ATLAS 160 : [-1.1, 2.6]** **CMS 045 : [-0.9, 2.8]**

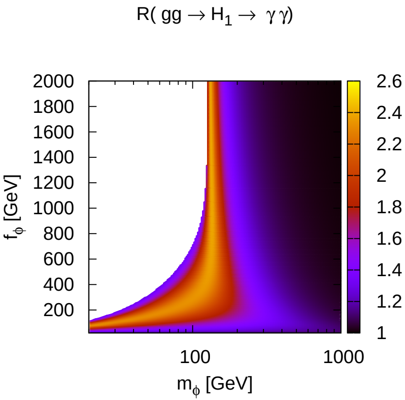

Figure: $\gamma\gamma$: ggF and VBF

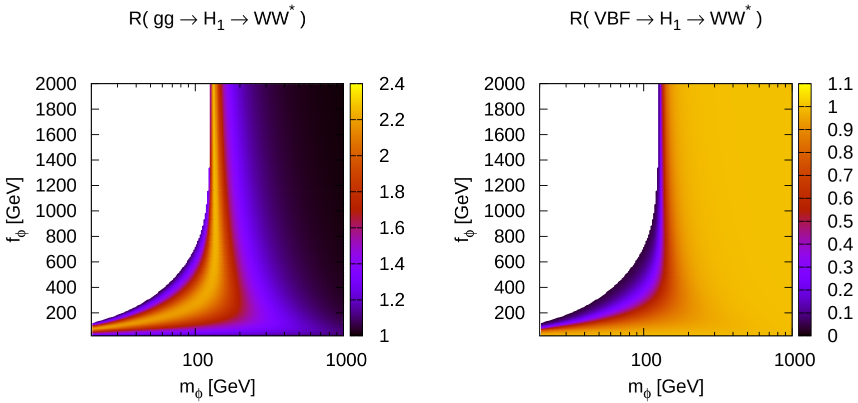

Figure: WW^*: ggF and VBF

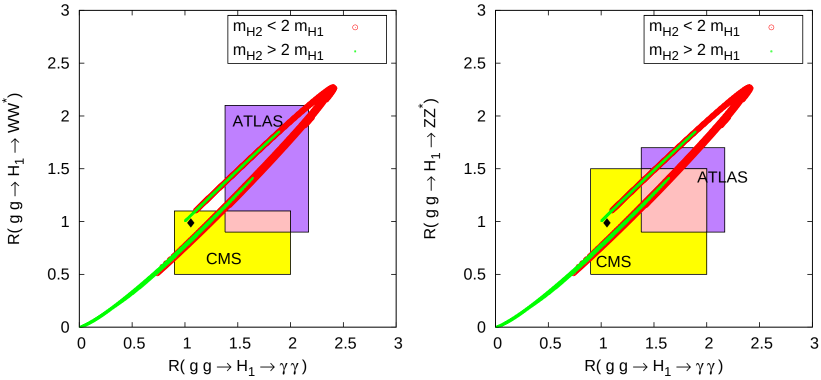

Figure: Correlations between diphoton and diboson

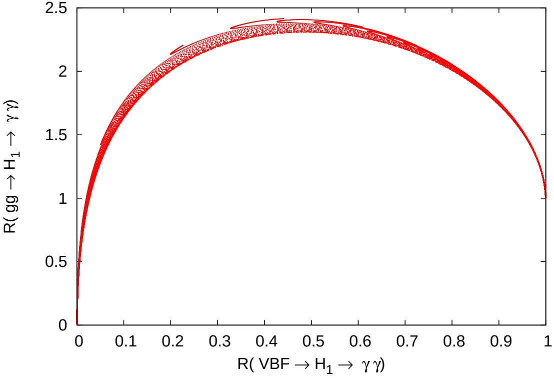

Figure: Correlation between *gg* and VBF

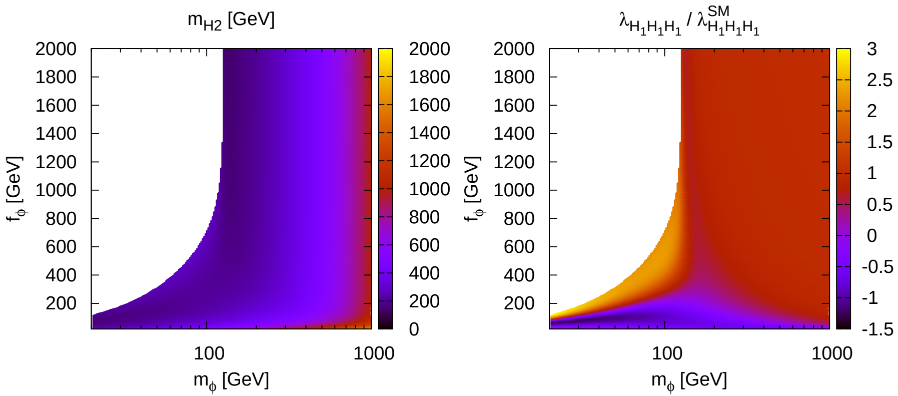

Figure: Heavy Higgs and triple couplings

Summary and Prospects

- **We consider the "minimal" Higgs-Dilaton mixing scenario.**
- **Consistent with the data until now.**
- **Generically, enhancement on the gg initiated process and mixing angle suppression for other process.**
- **If things are going well.....**
  - **Heavy Higgs phenomenology...?**
  - **Higgs pair production...?**
  - **EW precision test...?**
- **Let's wait and see!**

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