Contribution of Scalar Singlet and Dimension 5 operator in Higgs Physics

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Higgs boson in 4l channel
[www.atlasexperiment.org]

Higgs boson in diphoton channel
[cms.web.cern.ch]

- Its discovery verifies well established SM theory.
- Central piece of SM.
Motivation for Singlet Extension of SM

• One of the simplest extension of SM is by adding real scalar singlet.
• After EWSB, singlet mixes with SM Higgs as a result, shape of potential as well as Higgs coupling to SM particles are changed.
• New decay signature is observed: \( h_2 \rightarrow h_1 h_1 \)
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Further extension of SM

Further potential shape and Higgs coupling are altered with the inclusion of effective Lagrangian.

- The effective Lagrangian approach is a model-independent way to describe new physics (NP) at cut-off scale (\( \Lambda \)).
- Effective Lagrangian has higher dimension operator suppressed by some power of \( \Lambda \).
• The model contains SM and new physics (NP) Lagrangian.

\[ \mathcal{L} = \mathcal{L}_{SM} + \mathcal{L}_{s \leq 5} \]  \hspace{1cm} (1)

• \( \mathcal{L}_{s \leq 5} \) is NP Lagrangian up to dim 5 built from \((S)\) and SM fields.
• \( \mathcal{L}_{s \leq 5} \) can be split as scalar interaction up to dim 4 and effective interaction(\(\mathcal{L}_{5}^{s}\)) of dim 5.
Model

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Effective Lagrangian

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\[ \mathcal{L}^s_5 = - \frac{a_3}{2\Lambda} S^3(\Phi^\dagger \Phi) - \frac{a_4}{2\Lambda} S(\Phi^\dagger \Phi)^2 - \frac{b_5}{5\Lambda} S^5 + g_s^2 \frac{f^s_{GG}}{\Lambda} S G^a_{\mu\nu} G^{a \mu\nu} \]

\[ + \frac{e^2}{\cos^2 \theta_w} \frac{f^s_{BB}}{\Lambda} S B^a_{\mu\nu} B^{a \mu\nu} + \frac{e^2}{\sin^2 \theta_w} \frac{f^s_{WW}}{\Lambda} S W^a_{\mu\nu} W^{a \mu\nu} \]

\[ + \left( -\frac{f^s_d}{\Lambda} S \bar{Q}_L \Phi d_R - \frac{f^s_u}{\Lambda} S \bar{Q}_L \tilde{\Phi} u_R - \frac{f^s_l}{\Lambda} S \bar{L}_L \Phi l_R + h.c. \right) \] (2)
• With our model, we start with scattering amplitude of Higgs ($h_1$) to SM particle.

$$\mathcal{M} = \mathcal{M}_{SM} + \mathcal{M}_{dim=5}$$  \hspace{1cm} (3)

• The squared amplitude is

$$|\mathcal{M}|^2 = |\mathcal{M}_{SM}|^2 + |\mathcal{M}_{dim=5}|^2 + 2\text{Re}(|\mathcal{M}_{SM}||\mathcal{M}_{dim=5}|)$$

$$\sim \frac{1}{\Lambda^0} \quad \sim \frac{1}{\Lambda^2} \quad \sim \frac{1}{\Lambda^1}$$  \hspace{1cm} (4)

• The decay width has contribution from all three terms.
• We take SM and interference term only and see how branching ratios (BR) of Higgs are affected.
Result: BR of Higgs to $\gamma\gamma$ and $WW^*$

- BR of Higgs ($h_1$) to $\gamma\gamma$
  - BR down by approximately 40-50% compared to SM.
  - BR is more sensitive to $f_{WW}$ in $h_1 \rightarrow \gamma\gamma$ compared to $h_1 \rightarrow WW^*$

- BR of Higgs ($h_1$) to $WW^*$
  - BR down by approximately 5-7% compared to SM.

\[ \Lambda = 2 \text{TeV}, f_d = 0.01, f_u = 0.01, f_l = 0.01 \]


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Higgs ($h_1$) to $WW^*$
- BR down by approximately 5-7% compared to SM.

BR of Higgs to $b\bar{b}$ and $\tau^+\tau^-$

- BR increases by approximately 10-15% compared to SM.
- BR is more sensitive to effective fermionic coupling coefficient in $h_1 \rightarrow \tau^+\tau^-$ compared to $h_1 \rightarrow b\bar{b}$

Higgs to $b\bar{b}$
- BR increases by approximately 65-80% compared to SM.

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Variation of Higgs total width with $f_d$ and $f_{GG}$

- With increase in $f_d$ and $f_{GG}$, the total width also increases.
• The observed signal strength for Higgs production from gluon fusion is:

$$\mu_{ggF} = 1.03_{-1.14}^{+1.16}$$  \hspace{1cm} (5)

• The signal strength for Higgs decaying to final states are:

$$\mu_{\gamma\gamma} = 1.14_{-1.18}^{+1.19}$$

$$\mu_{ZZ} = 1.29_{-0.23}^{+0.26}$$

$$\mu_{WW} = 1.09_{-0.16}^{+0.18}$$  \hspace{1cm} (6)

$$\mu_{\tau\tau} = 1.11_{-0.22}^{+0.24}$$

$$\mu_{bb} = 0.70_{-0.27}^{+0.29}$$

• The observed signal strengths will put bounds on mixing angle and effective coupling coefficients.
Limits on Mixing angle and $f_{GG}$

95% CL allowed region of $\sin \theta$ and $f_{GG}$
Red is allowed region by a fit to $\mu_{ggF}$ and black to $\mu^{ii}$

Limits on Effective Coupling Coefficient ($f_{BB}$ and $f_{WW}$)

95% CL allowed region of $f_{BB}$ and $f_{WW}$

⇒ Red is allowed region by a fit to $\mu_{ggF}$ and black to $\mu^{ii}$.
⇒ With increase in mixing angle, the black region shrink.
Conclusion

- Adding real scalar singlet and dimension 5 operator into SM, we found Higgs physics deviated from SM sector.

- Using fit to observed signal strengths, we found the allowed regions of scalar mixing angle and effective coupling coefficients.
THANK YOU
Higgs to $Z\gamma$ and $ZZ^*$

\[ \Lambda = 2\text{TeV}, f_d = 0.0, f_u = 0.0, f_i = 0.0 \]

\[ f_{GG} = 0.01, \cos\theta = 0.94, f_{BB} = 0.005 \]
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Higgs to $\gamma\gamma$, $WW^*$, $b\bar{b}$, and $\tau^+\tau^-$

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Variation of Higgs total width with $f_d$

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