Contribution of Scalar Singlet and Dimension 5 operator in Higgs Physics

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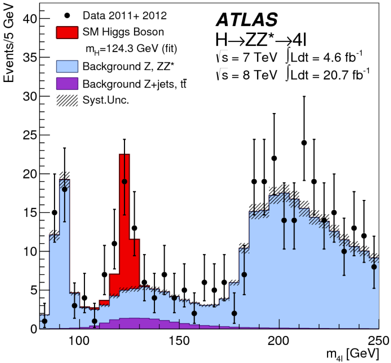
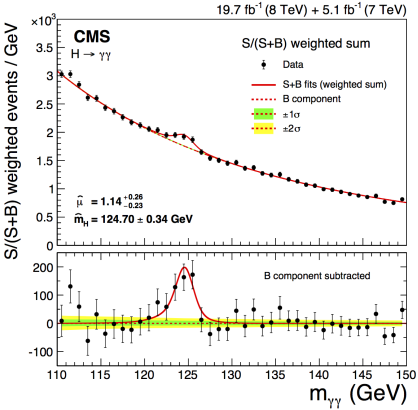
May 07, 2018

Higgs Boson



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

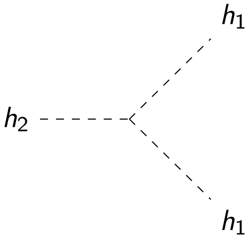


Higgs boson in diphoton channel [cms.web.cern.ch]

- 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: $h_2 \to h_1 h_1$



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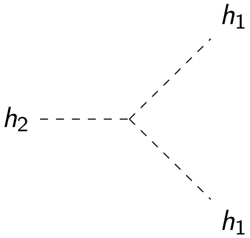

Further extention of SM

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 (Λ).
- Effective Lagrangian has higher dimension operator suppressed by some power of Λ.

Model

- The model contains SM and new physics(NP) Lagrangian.

$$\mathcal{L} = \mathcal{L}_{SM} + \mathcal{L}^{s}_{\leq 5} \qquad (1)$$

- $\mathcal{L}^{s}_{\leq 5}$ 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($\mathcal{L}^{s}_{5}$) of dim 5.

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Effective Lagrangian

[M. Bauer, A. Butter, J. Gonzalez-Fraile, T. Plehn, and M. Rauch,Phys. Rev., vol. D95, no. 5, p. 055011, 2017]

$$\begin{aligned}\mathcal{L}^{s}_{5} = & -\frac{a_3}{2\Lambda}S^3(\Phi^\dagger\Phi) - \frac{a_4}{2\Lambda}S(\Phi^\dagger\Phi)^2 - \frac{b_5}{5\Lambda}S^5 + g_s^2\frac{f^s_{GG}}{\Lambda}SG^a_{\mu\nu}G^{a\ \mu\nu} \\ & + \frac{e^2}{cos^2\theta_w}\frac{f^s_{BB}}{\Lambda}SB_{\mu\nu}B^{\mu\nu} + \frac{e^2}{sin^2\theta_w}\frac{f^s_{WW}}{\Lambda}SW^a_{\mu\nu}W^{a\ \mu\nu} \\ & + (-\frac{f^s_d}{\Lambda}S\bar{Q}_L\Phi d_R - \frac{f^s_u}{\Lambda}S\bar{Q}_L\tilde{\Phi}u_R - \frac{f^s_l}{\Lambda}S\bar{L}_L\Phi l_R + h.c)\end{aligned} \quad (2)$$

Procedure to Compute Decay Width

• With our model, we start with scattering amplitude of Higgs (h_1) to SM particle.

$$\mathcal{M} = \mathcal{M}_{SM} + \mathcal{M}_{dim=5} \tag{3}$$

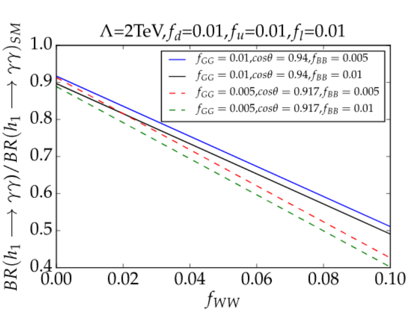
• The squared amplitude is

$$\underbrace{\mid \mathcal{M} \mid^2 = \mid \mathcal{M}_{SM} \mid^2}_{\sim \frac{1}{\Lambda^0}} + \underbrace{\mid \mathcal{M}_{dim=5} \mid^2}_{\sim \frac{1}{\Lambda^2}} + \underbrace{2Re(\mid \mathcal{M}_{SM} \mid \mid \mathcal{M}_{dim=5} \mid)}_{\sim \frac{1}{\Lambda^1}} \tag{4}$$

• The decay width has contribution from all three terms.

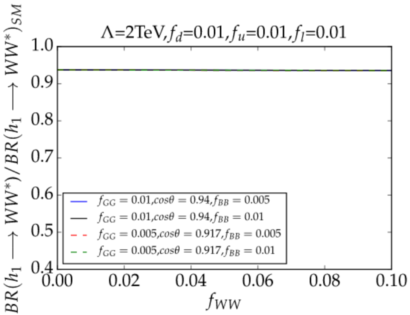
• We take SM and interference term only and see how branching ratios (BR) of Higgs are effected.

Result: BR of Higgs to $\gamma\gamma$ and WW^*



Higgs (h_1) to $\gamma\gamma$

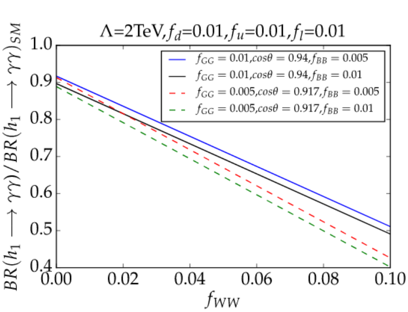
- BR down by approximately 40-50% compared to SM.

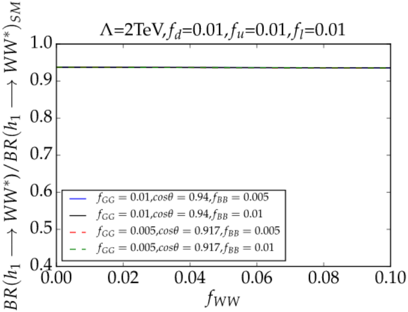


Higgs (h_1) to WW^*

- BR down by approximately 5-7% compared to SM.

- BR is more sensitive to f_{WW} in $h_1 \to \gamma\gamma$ compared to $h_1 \to WW^*$





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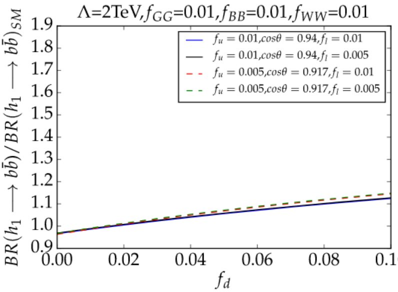
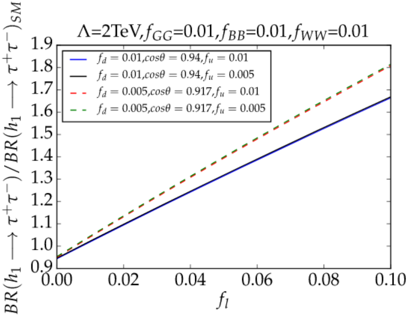
[S. Dawson and I. M. Lewis, Phys. Rev., vol. D95, no. 1, p. 015004, 2017]

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





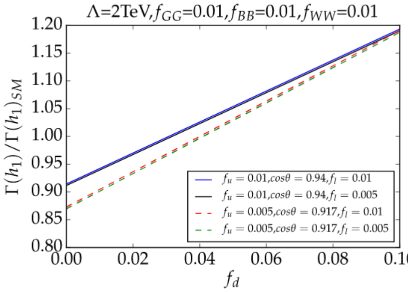
Higgs to $b\bar{b}$

- BR increases by approximately 10-15% compared to SM.

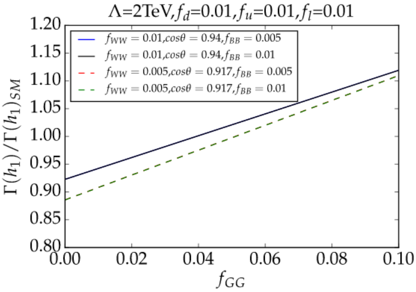
Higgs to $\tau^+\tau^-$

- BR increases by approximately 65-80% compared to SM.

- BR is more sensitive to effective fermionic coupling coefficient in $h_1 \rightarrow \tau^+\tau^-$ compared to $h_1 \rightarrow b\bar{b}$



Variation of Higgs total width with f_d



Variation of Higgs total width with f_{GG}

- With increase in f_d and f_{GG}, the total width also increases.

Constraints from Higgs Measurements ($\sqrt{s}$=7 and 8 TeV) [arxiv:1606.02266]

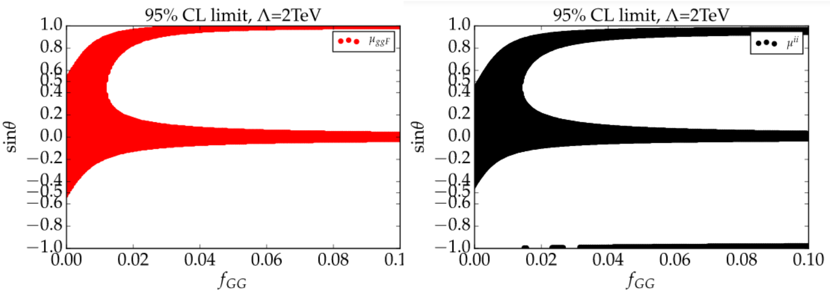
- The observed signal strength for Higgs production from gluon fusion is:

$$\mu_{ggF} = 1.03^{.16}_{-.14} \tag{5}$$

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

$$\begin{aligned} \mu^{\gamma\gamma} &= 1.14^{.19}_{-.18} \\ \mu^{ZZ} &= 1.29^{.26}_{-.23} \\ \mu^{WW} &= 1.09^{.18}_{-.16} \\ \mu^{\tau\tau} &= 1.11^{.24}_{-.22} \\ \mu^{bb} &= 0.70^{.29}_{-.27} \end{aligned} \tag{6}$$

- The observed signal strengths will put bounds on mixing angle and effective coupling coefficients.

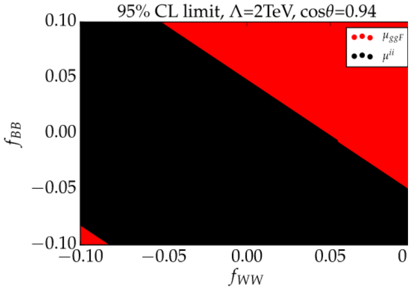


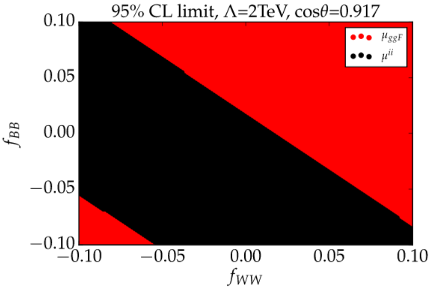
95% CL allowed region of $\sin\theta$ and f_{GG}

Red is allowed region by a fit to μ_{ggF} and black to μ^{ii}

[S. Dawson and I. M. Lewis, Phys. Rev., vol. D95, no. 1, p. 015004, 2017]

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





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

$\Rightarrow$Red is allowed region by a fit to μ_{ggF} and black to μ^{ii}.

$\Rightarrow$With increase in mixing angle, the black region shrink.

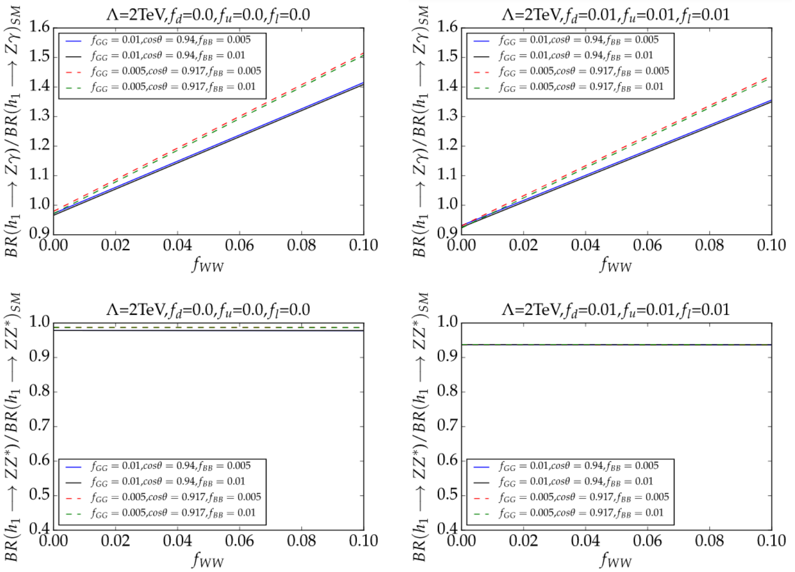
Conclusion

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

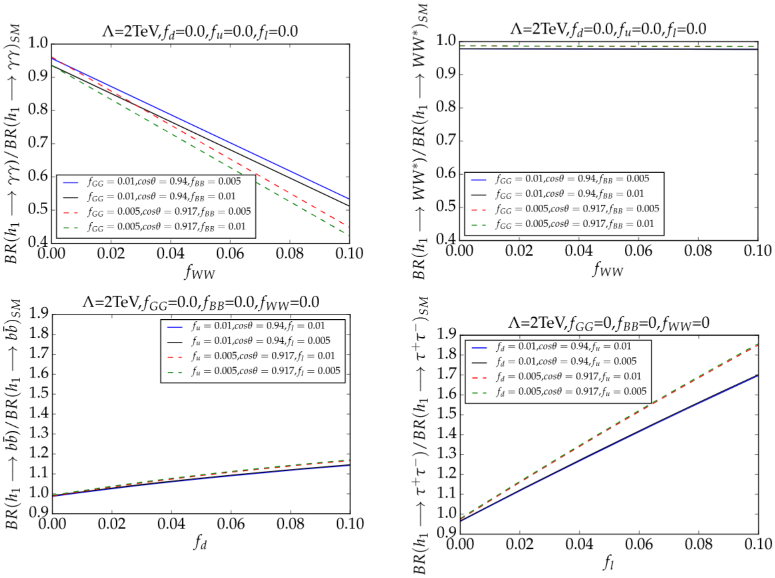
• Using fit to observed signal strengths, we found the allowed regions of scalar mixing angle and effective coupling coefficients.

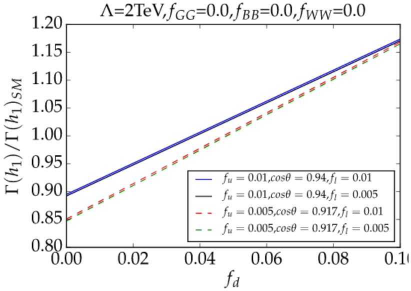
THANK YOU

Higgs to $Z\gamma$ and ZZ^*



Higgs to $\gamma\gamma$, WW^*, $b\bar{b}$, and $\tau^+\tau^-$





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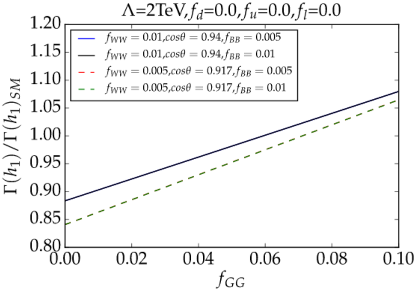

Variation of Higgs total width with f_{GG}