Single Higgs production at LHC as a probe for an anomalous Higgs self coupling

Pier Paolo Giardino
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Chicago

Based on
arXiv:1607.0425 [hep-ph];

Giuseppe Degrassi, P.P.G, Fabio Maltoni, Davide Pagani.
Framework

\[ V(\phi) = -\mu^2 \phi^\dagger \phi + \lambda (\phi^\dagger \phi)^2 \]

\[ V(H) = \frac{1}{2} M_H^2 H^2 + \frac{M_H^2}{2v} H^3 + \frac{M_H^2}{8v^2} H^4 \]
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How can we exclude an anomalous trilinear?

(maybe with the wrong sign)
**Higgs Pair Production**

- Very small Cross Section.
  - Heavier final state.
  - Additional weak coupling.
- At least one Higgs into bottoms.

\[
\begin{align*}
\text{at least one Higgs into bottoms.} \\
\text{Assuming no change in the other Higgs couplings, ATLAS and CMS at 8 TeV exclude the regions} \\
(-\infty, -12] \cup [17, \infty) \\
(-\infty, -17.5] \cup [22.5, \infty) \\
\text{At 3000 fb}^{-1} \text{ the exclusion region should be} \\
(-\infty, -1.3] \cup [8.7, \infty)
\end{align*}
\]

\[gg \to H \sim 50 \text{ pb (13 TeV)}
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\[gg \to HH \sim 35 \text{ fb (13 TeV)}
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The modification of the trilinear could be described in a $\kappa$-framework

$$V_{H^3} = \lambda_3 v H^3 \equiv \kappa \lambda_3^{SM} v H^3$$

For similar ideas:

M. McCullough Phys. Rev. D90 (2014), no. 1 015001
Single Higgs

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Due to the presence of different Loop structures these contributions cannot be captured by a local rescaling.

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$C_1$ coefficients

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Higgs wave function renormalization
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Amplitudes generated by FeynArts, computed by FormCalc interfaced to Loop-Tools, checked with FeynCalc.
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We computed the correction with an asymptotic expansion in large top mass.

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<th>$C_1^\sigma$ [%]</th>
<th>$ggF$</th>
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**Legend for Diagram:**
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Here $\delta \sigma_\lambda$ is the same of the SM ($\kappa_\lambda=1$)
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![Graph showing the variation of BR with $\kappa_3$ for different processes]
The corrections to BR are smaller than the ones to the $\Gamma$. 

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However the (positive) $\delta$BR are usually larger than the $\delta\sigma$.

In other words, in the range close to the SM, the decays are more sensitive to $\kappa_\lambda$ than the production processes.

$$\delta BR_{\lambda_3}(i) = \frac{(\kappa_\lambda - 1)(C_1^\Gamma(i) - C_1^{\Gamma_{tot}})}{1 + (\kappa_\lambda - 1)C_1^{\Gamma_{tot}}}$$
All the available Single Higgs processes depend on the single Parameter $\kappa_\lambda$. So in principle a global fit can be very powerful in constraining the Higgs trilinear coupling.
Constraints on $\lambda$: present

$$
\chi^2(\kappa_\lambda) \equiv \sum_{\mu_i} \frac{(\mu_i^f(\kappa_\lambda) - \bar{\mu}_i^f)^2}{(\Delta(\kappa_\lambda))^2}
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$$\chi^2(\kappa, \lambda) \equiv \sum_{i} \frac{(\mu^f_i(\kappa, \lambda) - \bar{\mu}^f_i)^2}{(\Delta(\kappa, \lambda))^2}$$

In this fit we consider different “scenarios”.

Data from arXiv:1606.02266

ATLAS-CMS 8 TeV data combination
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For ggF+VBF: $\kappa_{\lambda}^{\text{best}} = -0.24$

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Requiring $p>0.05$ we are able to exclude, at more than 2 $\sigma$, that a model with an anomalous coupling can explain the data if $\kappa_{\lambda} < -14.26$
Using the uncertainties presented in arXiv:1312.4974, and assuming that LHC will measure SM, we can estimate the future capabilities of LHC.
Constraints on $\lambda$: future

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For CMS-HL-II 3000 fb$^{-1}$

$$\kappa_1^{\lambda} = [-0.75, 4.23] \quad \kappa_2^{\lambda} = [-1.99, 6.77]$$

$$\kappa_\lambda^{P>0.05} = [-4.10, 9.77]$$
Constraints on $\lambda$: future

A more reliable approach is to consider central values compatible with SM.

We produce a collection of pseudo-measurements randomly generated with a gaussian distribution around the SM.

1) best values, 2) $1\sigma$ region lower limit, 3) $1\sigma$ region upper limit, 4) $2\sigma$ region lower limit, 5) $2\sigma$ region upper limit, 6) $p > 0.05$ region lower limit, 7) $p > 0.05$ region upper limit, 8) $1\sigma$ region width, 9) $2\sigma$ region width, 10) $p > 0.05$ region width.
Constraints on $\lambda$: future(!?!) 

An interesting scenario is the one where the uncertainties are 1% for all the channels.

As expected a precise measurement of the $ttH$ would lead to a sizeable improvement in the fit.
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- Compared to Higgs pair production, the bounds obtained are competitive and complementary.
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  - however the condition for the other couplings to be SM can be lifted.
- The biggest role is played by the top-top-Higgs associated production.