Constraining the Higgs boson self-coupling via single-Higgs production measurements

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Constraints on the Higgs boson self-coupling, $\lambda_{HHH}$, exploiting measurements of the single-Higgs boson production and decays are reported in this contribution. The Higgs boson cross sections, the branching fractions and the Higgs boson kinematics are affected by the Higgs-boson self coupling contribution through Next-to-Leading Order electroweak corrections. The results are obtained using up to 80 fb$^{-1}$ of LHC proton-proton collision data at $\sqrt{s} = 13$ TeV collected with the ATLAS experiment, combining the data of the analyses targeting the $\gamma\gamma$, $ZZ^*$, $WW^*$, $\tau\tau$ and $b\bar{b}$ decay channels and using both inclusive and differential information. In the simplified assumption that all deviations from the SM expectation have to be interpreted as modifications of the trilinear coupling of the Higgs boson, the best fit value of $\kappa_\lambda$, defined as the ratio $\kappa_\lambda = \lambda_{HHH}/\lambda_{HHH}^{SM}$, is $\kappa_\lambda = 4.0^{+4.3}_{-1.4}$, excluding at the 95% confidence level values outside the interval $-3.2 < \kappa_\lambda < 11.9$.

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1. Introduction

The most recent constraints on the Higgs boson trilinear self-coupling, $\lambda_{HHH}$, have been set in the context of direct searches of Higgs boson pairs at the LHC. Results are reported in terms of the ratio of the Higgs boson self-coupling to its Standard Model (SM) expectation, i.e. $\kappa_\lambda = \lambda_{HHH}/\lambda_{HHH}^{SM}$. Using up to 36 fb$^{-1}$ of Run 2 data, it is constrained by ATLAS [1] to lie in the interval $-5.0 < \kappa_\lambda < 12.0$ at 95% CL [2].

An alternative and complementary approach to study the Higgs boson self-coupling has been proposed in Refs. [3, 4], exploiting the dependence of single Higgs processes on $\lambda_{HHH}$ at NLO EW via Higgs self-energy loop corrections and additional diagrams. The results are obtained using ATLAS data corresponding to a luminosity of up to 80 fb$^{-1}$ and using single-Higgs production, combining the data of the analyses targeting the $\gamma\gamma$, $ZZ^*$, $WW^*$, $\tau\tau$ and $b\bar{b}$ decay channels.

2. Theoretical model

References [3, 4] propose a framework for a global fit to constrain the Higgs boson trilinear coupling that scales with $\kappa_\lambda$ and affects Higgs boson production cross-sections, decay rates and kinematic distributions:

$$\mu_i(\kappa_\lambda, \kappa_i) = \frac{\sigma_{BSM}}{\sigma_{SM}} = Z_H^{BSM}(\kappa_\lambda) \left[ \kappa_i^2 + \frac{(\kappa_i - 1)C_i^1}{K_{EW}^i} \right],$$

$$\mu_f(\kappa_\lambda, \kappa_f) = \frac{BR_{BSM}^f}{BR_{SM}^f} = \frac{\kappa_f^2 + (\kappa_f - 1)C_f^1}{\sum_j BR_{BSM}^j \left[ \kappa_j^2 + (\kappa_j - 1)C_j^1 \right]} ,$$

where:

- $\mu_i$ and $\mu_f$ are the production cross section $\sigma_i$ and the $BR_f$ normalised to their SM values, respectively;
- $Z_H^{BSM}(\kappa_\lambda)$ is defined as: $Z_H^{BSM}(\kappa_\lambda) = \frac{1}{1-(\kappa_\lambda - 1)\delta Z_H}$;
- $\kappa_i$ and $\kappa_f$ represent multiplicative modifiers to other Higgs boson couplings for initial and final states, parameterised as in the LO $\kappa$-framework;
- $C_i^1$ are the process-dependent corrections linearly proportional to $\lambda_{HHH}$, different for each process and kinematic distribution;
- the differential $C_i^1$ coefficients for each region of the simplified template cross section (STXS) framework, defined in Ref. [5], for the VBF, WH and ZH production modes are reported in Ref. [6] while the inclusive $C_i^1$ coefficients are taken from Refs. [3, 4].

3. Results of the fit to $\kappa_\lambda$

A likelihood fit is performed in the theoretically allowed [3, 4] range $-20 < \kappa_\lambda < 20$ to constrain the value of the Higgs boson self-coupling $\kappa_\lambda$, setting all other Higgs boson couplings to
their SM values. The value of \(-2 \ln \Lambda(\kappa)\) as a function of \(\kappa\) is shown in Figure 1 for the data in (a) and the Asimov dataset [7] generated in the SM hypothesis in (b). The central value and uncertainty of \(\kappa\) are determined to be [6]:

\[
\kappa = 4.0^{+4.3}_{-4.1} = 4.0^{+3.7}_{-3.6} \text{(stat)}^{+1.6}_{-1.5} \text{(exp)}^{+1.3}_{-0.9} \text{(sig.th.)}^{+0.8}_{-0.5} \text{(bkg. th.)},
\]

where the total uncertainty is decomposed into components for statistical uncertainties, experimental systematic uncertainties, and theory uncertainties on signal and background modelling. The 95\% CL interval of \(\kappa\) is \(-3.2 < \kappa < 11.9\) (observed) and \(-6.2 < \kappa < 14.4\) (expected).

![Figure 1](image-url)

**Figure 1**: Profile likelihood scan performed as a function of \(\kappa\) on data (a) and on the Asimov dataset (b). The solid black line shows the profile likelihood distributions obtained including all systematic uncertainties (“Total”). Results from a statistic only fit “Stat. only” (black dashed line), including the experimental systematics “Stat. + Exp. Sys.” (blue solid line), adding theory systematics related to the signal “Stat.+ Exp. Sys.+ Sig. Th. Sys.” (red solid line) are also shown [6].

The dominant contributions to the \(\kappa\) sensitivity derive from the di-boson decay channels \(\gamma\gamma\), \(ZZ^*\), \(WW^*\) and from the \(ggF\) and \(t\bar{t}H\) production modes as shown in Figure 2.

### 4. Results of the fit to \(\kappa\) and either \(\kappa_F\) or \(\kappa_V\)

A simultaneous fit is performed to \((\kappa_\lambda, \kappa_F)\) and \((\kappa_\lambda, \kappa_V)\), where \(\kappa_F\) and \(\kappa_V\) are the modifiers of the Higgs boson coupling to fermions and to massive vector bosons, respectively. Figure 3 (a) and (b) shows negative log-likelihood contours on the \((\kappa_\lambda, \kappa_F)\) and \((\kappa_\lambda, \kappa_V)\) grids obtained from fits performed for the \(\kappa_V=1\) or \(\kappa_F=1\) hypothesis, respectively. These fits target beyond SM physics scenarios where new physics could affect only the Yukawa type terms \(\kappa_V=1\) of the SM or only the couplings to vector bosons \(\kappa_F=1\), in addition to the Higgs boson self-coupling \(\kappa_\lambda\). Including additional degrees of freedom to the fit reduces the constraining power of the measurement. An even less constrained fit, performed by fitting simultaneously \(\kappa_\lambda, \kappa_F\) and \(\kappa_V\), results in nearly no sensitivity to \(\kappa_\lambda\) within the theoretically allowed range of \(|\kappa_\lambda| < 20\).
when a single overall Higgs coupling rescaling modifier is considered. The di-degeneracies nor to improve the sensitivity to that is not far from to the more direct determination of the Higgs boson self-coupling through double self-coupling and single Higgs boson couplings to either fermions or bosons, have also been derived.

\( \lambda \)

The theory parametrization used in this study in terms of cross section dependence on

\( \sigma \)

Figure 5:

Figure 2: Profile likelihood scan performed as a function of \( \kappa_\lambda \) on Asimov datasets for each production mode (a) and decay channel (b) [6].

Figure 3: 2D contours at 68% and 95% CL in the \( (\kappa_\lambda, \kappa_\nu) \) plane under the assumption of \( \kappa_\nu = 1 \) (a) and in the \( (\kappa_\lambda, \kappa_\nu) \) plane under the assumption of \( \kappa_\nu = 1 \) (b) [6].

5. Conclusion

An alternative and complementary approach to constrain the Higgs boson self-coupling through single-Higgs processes has been applied to the combination of analyses targeting the single-Higgs production modes on data collected with the ATLAS experiment using up to 80 fb\(^{-1}\) of LHC proton-proton collisions. In the simplified assumption that all deviations from the SM expectation have to be interpreted as modifications of the trilinear coupling of the Higgs boson, the Higgs boson self-coupling modifier \( \kappa_\lambda = \lambda_{HHH}/\lambda_{HHH}^{SM} \), extracted with a global fit procedure, is determined to be \( \kappa_\lambda = 4.0^{+4.3}_{-4.1} \), excluding at the 95% CL values outside the interval 3.2 < \( \kappa_\lambda \) < 11.9.
References

[1] ATLAS Collaboration: The ATLAS Experiment at the CERN Large Hadron Collider, JINST3 S08003, 2008;


