PROCEEDINGS OF SCIENCE

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

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Constraints on the Higgs boson self-coupling, λ_{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 κ_λ, defined as the ratio $\kappa_\lambda = \lambda_{HHH}/\lambda_{HHH}^{SM}$, is $\kappa_\lambda = 4.0^{+4.3}_{-4.1}$, 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, λ_{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, 5], exploiting the dependence of single Higgs processes on λ_{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 [4, 5] propose a framework for a global fit to constrain the Higgs boson trilinear coupling that scales with κ_λ and affects Higgs boson production cross-sections, decay rates and kinematic distributions:

$$\mu_i(\kappa_\lambda,\kappa_i) = \frac{\sigma^{BSM}}{\sigma^{SM}} = Z_H^{BSM}(\kappa_\lambda)\left[\kappa_i^2 + \frac{(\kappa_\lambda-1)C_1^i}{K_{EW}^i}\right],$$
$$\mu_f(\kappa_\lambda,\kappa_f) = \frac{BR_f^{BSM}}{BR_f^{SM}} = \frac{\kappa_f^2+(\kappa_\lambda-1)C_1^f}{\sum_j BR_j^{SM}\left[\kappa_j^2+(\kappa_\lambda-1)C_1^j\right]},$$

where:

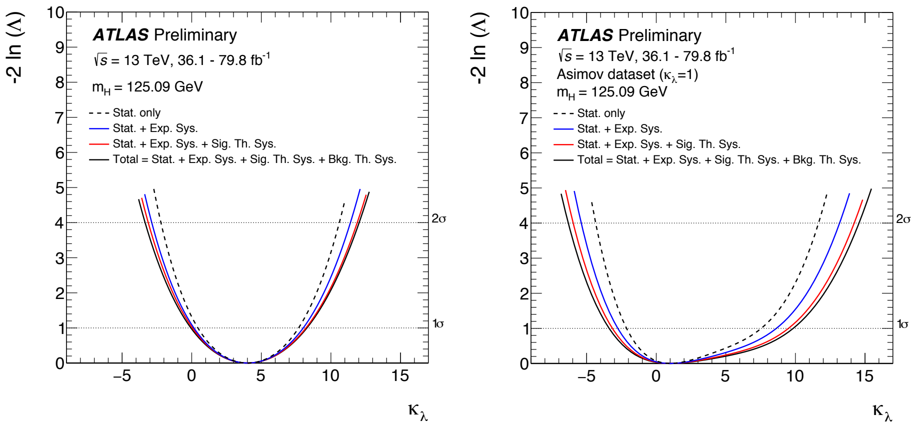
- μ_i and μ_f are the production cross section σ_i and the BR_f normalised to their SM values, respectively;
- $Z_H^{BSM}(\kappa_\lambda)$ is defined as: $Z_H^{BSM}(\kappa_\lambda) = \frac{1}{1-(\kappa_\lambda^2-1)\delta Z_H}$;
- κ_i and κ_f represent multiplicative modifiers to other Higgs boson couplings for initial and final states, parameterised as in the LO κ-framework;
- C_1^i are the process-dependent corrections linearly proportional to λ_{HHH}, different for each process and kinematic distribution;
- the differential C_1^i coefficients for each region of the simplified template cross section (STXS) framework, defined in Ref. [6], for the VBF, WH and ZH production modes are reported in Ref. [7] while the inclusive C_1^i coefficients are taken from Refs. [4, 5].

3. Results of the fit to κ_λ

A likelihood fit is performed in the theoretically allowed [4, 5] range -20 $< \kappa_\lambda <$ 20 to constrain the value of the Higgs boson self-coupling κ_λ, setting all other Higgs boson couplings to their SM values. The value of -2 ln $\Lambda(\kappa_\lambda)$ as a function of κ_λ is shown in Figure 1 for the data in (a) and the Asimov dataset [8] generated in the SM hypothesis in (b). The central value and uncertainty of κ_λ are determined to be [7]:

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

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 κ_λ is -3.2 $< \kappa_\lambda <$ 11.9 (observed) and -6.2 $< \kappa_\lambda <$ 14.4 (expected).



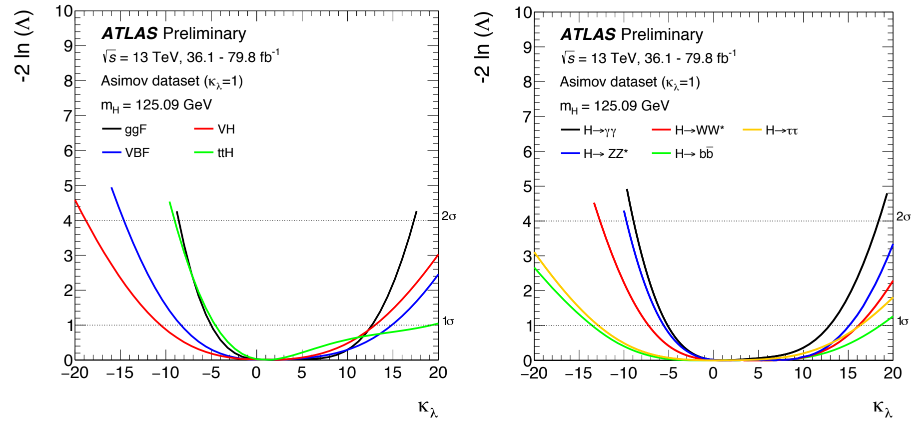
(a) (b)

Figure 1: Profile likelihood scan performed as a function of κ_λ 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 [7].

The dominant contributions to the κ_λ 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.

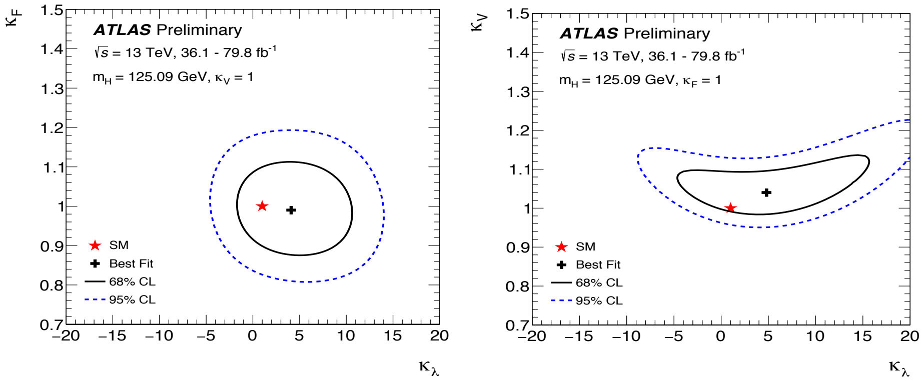
4. Results of the fit to κ_λ and either κ_F or κ_V

A simultaneous fit is performed to (κ_λ, κ_F) and (κ_λ, κ_V), where κ_F and κ_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 (κ_λ, κ_F) and (κ_λ, κ_V) grids obtained from fits performed for the κ_V=1 or κ_F=1 hypothesis, respectively. These fits target beyond SM physics scenarios where new physics could affect only the Yukawa type terms (κ_V= 1) of the SM or only the couplings to vector bosons (κ_F= 1), in addition to the Higgs boson self-coupling (κ_λ). Including additional degrees of freedom to the fit reduces the constraining power of the measurement. An even less constrained fit, performed by fitting simultaneously κ_λ, κ_F and κ_V, results in nearly no sensitivity to κ_λ within the theoretically allowed range of $|\kappa_\lambda| < 20$.



(a) (b)

Figure 2: Profile likelihood scan performed as a function of κ_λ on Asimov datasets for each production mode (a) and decay channel (b) [7].



(a) (b)

Figure 3: 2D contours at 68% and 95% CL in the $(\kappa_\lambda, \kappa_F)$ plane under the assumption of $\kappa_V = 1$ (a) and in the $(\kappa_\lambda, \kappa_V)$ plane under the assumption of $\kappa_F = 1$ (b) [7].

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 $3.2 < \kappa_\lambda < 11.9$.

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