

## Constraining the Higgs boson self-coupling with single-Higgs and double-Higgs production measurements

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**Summary.** — One of the most important targets of the LHC is to improve the experimental results of the Run 1 and the complete exploration of the properties of the Higgs boson, in particular the Higgs boson self-coupling. The self-coupling,  $\lambda_{HHH}$ , is very loosely constrained by electroweak (EW) precision measurements, therefore new physics (NP) effects could induce large deviations from its Standard Model (SM) expectation. Constraints on  $\kappa_\lambda$ , defined as the ratio  $\kappa_\lambda = \lambda_{HHH}/\lambda_{HHH}^{SM}$ , are set using up to  $80 \text{ fb}^{-1}$  of LHC  $pp$  collision data at  $\sqrt{s} = 13 \text{ TeV}$  collected with the ATLAS experiment. Single-Higgs results exploit the combination of the analyses targeting the  $\gamma\gamma$ ,  $ZZ^*$ ,  $WW^*$ ,  $\tau^+\tau^-$  and  $b\bar{b}$  decay channels and use both inclusive and differential information, while double-Higgs results exploit the combination of the analyses targeting the  $b\bar{b}\gamma\gamma$ ,  $b\bar{b}\tau^+\tau^-$  and  $b\bar{b}b\bar{b}$  decay channels. From single-Higgs measurements, values outside the interval  $-3.2 < \kappa_\lambda < 11.9$  are excluded at the 95% confidence level (CL) under the assumption that NP affects only the Higgs self-coupling. This interval is comparable to the one obtained from double-Higgs measurements, *i.e.*,  $-5.0 < \kappa_\lambda < 11.9$ .

### 1. – Introduction

Constraints on the Higgs boson self-coupling have been set by ATLAS in the context of direct searches for double-Higgs production, combining  $b\bar{b}\gamma\gamma$ ,  $b\bar{b}\tau^+\tau^-$  and  $b\bar{b}b\bar{b}$  decay channels and using up to  $36 \text{ fb}^{-1}$  of Run 2 data [1]. Exclusion limits have been set after a  $\kappa_\lambda$ -scan on the  $\sigma_{ggF}(pp \rightarrow HH)$  cross section and a comparison with the theoretical cross section as a function of  $\kappa_\lambda$ , thus leading to a  $\kappa_\lambda$  constrained at 95% CL in the interval  $-5.0 < \kappa_\lambda < 12.0$ . An alternative and complementary approach to study the Higgs boson self-coupling has been proposed in refs. [2, 3] exploiting the fact that single-Higgs processes are sensitive to  $\lambda_{HHH}$  via loop corrections; these corrections affect inclusive single-Higgs cross sections, Higgs boson kinematics and decay branching fractions, while double-Higgs cross section and kinematics are affected by the self-coupling contribution at leading order in EW interactions. Constraints on  $\kappa_\lambda$  are thus extracted from both

single-Higgs and double-Higgs measurements where, for the latter, the dependence on  $\kappa_\lambda$  of the branching fractions and of the single-Higgs background is included.

## 2. – Results of fit to $\kappa_\lambda$ : Single-Higgs production measurements

In the simplified assumption that NP is expected to appear only as a modification of the Higgs boson self-coupling,  $\kappa_\lambda$  is constrained at 95% CL to be in the interval  $-3.2 < \kappa_\lambda < 11.9$ , through a global-likelihood fit in the theoretically allowed [2,3] range  $-20 < \kappa_\lambda < 20$  and setting all other Higgs boson couplings to their SM values.

The central value and uncertainty of  $\kappa_\lambda$  are determined to be [4]

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

where the total uncertainty is decomposed into components for statistical uncertainties, experimental systematic uncertainties, and theory uncertainties on signal and background modelling.

The dominant contributions to the  $\kappa_\lambda$  sensitivity derive from the  $ggF$  and  $t\bar{t}H$  production modes and from the di-boson decay channels  $\gamma\gamma$ ,  $ZZ^*$ ,  $WW^*$  [4].

When modifications of the single-Higgs couplings are taken into account, and additional degrees of freedom are included in the fit, the constraints on  $\kappa_\lambda$  become weaker.

## 3. – Results of fit to $\kappa_\lambda$ : Double-Higgs production measurements

In this work, a different approach has been used with respect to ref. [1]: a likelihood function, where  $\kappa_\lambda$  is the parameter of interest, has been built and both single-Higgs background and branching fractions have been parameterised to include loop corrections depending on  $\kappa_\lambda$ . The 95% CL interval of  $\kappa_\lambda$  is  $-5.0 < \kappa_\lambda < 11.9$ , leading to a significant improvement of single channel performance as a result of the comparable sensitivity, as shown in fig. 1 for data (left) and for the Asimov dataset (right). The peculiar likelihood

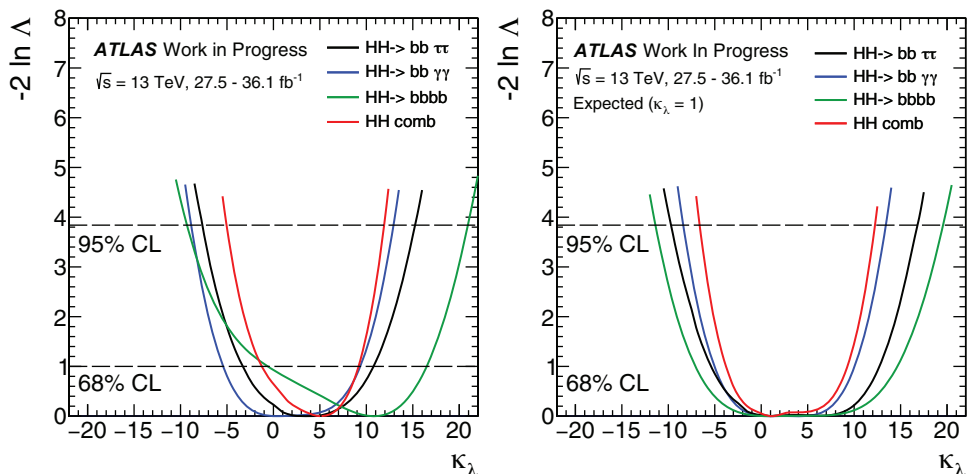


Fig. 1. – Profile likelihood scan for data (left) and for the Asimov dataset (right) performed as a function of  $\kappa_\lambda$ , considering double-Higgs single channels and their combination.

function structure, characterised by the two local minima, is related to the dependence of the total cross section and double-Higgs kinematic properties on  $\kappa_\lambda$ .

#### 4. – Conclusion

An alternative approach to constrain the Higgs boson self-coupling through single-Higgs measurements has been probed to be competitive with direct double-Higgs measurements, constraining  $\kappa_\lambda$  in the interval  $-3.2 < \kappa_\lambda < 11.9$  at 95% CL, assuming that NP affects only the Higgs boson self-coupling. This approach has been exploited also in double-Higgs processes with the final target of combining single- and double-Higgs measurements; loop corrections as a function of  $\kappa_\lambda$  have been implemented in the branching fractions and in the single-Higgs background, in addition to the dependence on  $\kappa_\lambda$  included in the double-Higgs cross section and kinematics; thus values outside the interval  $-5.0 < \kappa_\lambda < 11.9$  are excluded at 95% CL.

#### REFERENCES

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