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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, λ_{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 κ_λ, defined as the ratio $\kappa_\lambda = \lambda_{HHH}/\lambda_{HHH}^{SM}$, are set using up to 80 fb^{-1} of LHC pp collision data at $\sqrt{s} = 13$ 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 fb^{-1} of Run 2 data [1]. Exclusion limits have been set after a κ_λ-scan on the $\sigma_{ggF}(pp \to HH)$ cross section and a comparison with the theoretical cross section as a function of κ_λ, thus leading to a κ_λ 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 λ_{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 κ_λ are thus extracted from both

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

2. – Results of fit to κ_λ: Single-Higgs production measurements

In the simplified assumption that NP is expected to appear only as a modification of the Higgs boson self-coupling, κ_λ 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 κ_λ 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 κ_λ 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 κ_λ become weaker.

3. – Results of fit to κ_λ: Double-Higgs production measurements

In this work, a different approach has been used with respect to ref. [1]: a likelihood function, where κ_λ 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 κ_λ. The 95% CL interval of κ_λ 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

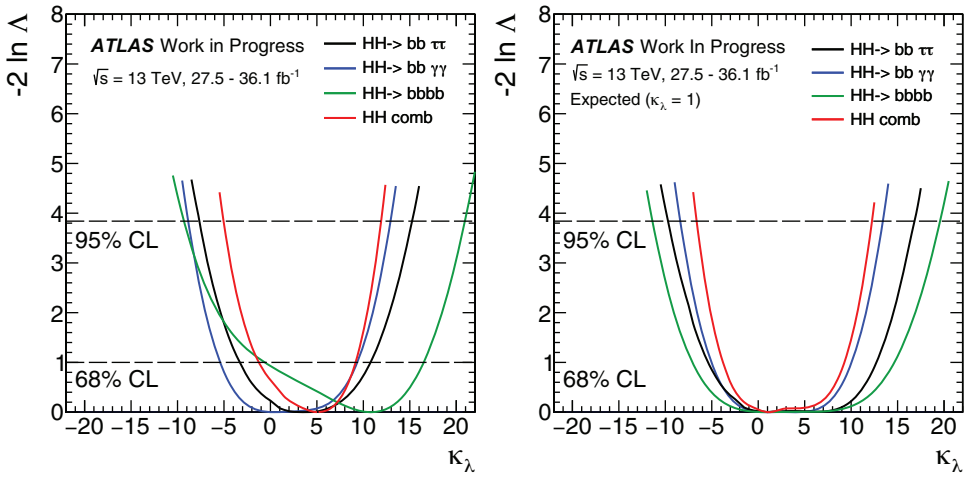

Fig. 1. – Profile likelihood scan for data (left) and for the Asimov dataset (right) performed as a function of κ_λ, considering double-Higgs single channels and their combination.

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

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 κ_λ 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 κ_λ have been implemented in the branching fractions and in the single-Higgs background, in addition to the dependence on κ_λ 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.

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