PROCEEDINGS OF SCIENCE

Constraints on the Higgs boson self-coupling from the combination of single-Higgs and double-Higgs production analyses performed with the ATLAS experiment

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Constraints on the Higgs boson self-coupling are set by combining the single Higgs boson analyses targeting the $\gamma\gamma$, ZZ^*, WW^*, $\tau^+\tau^-$ and $b\bar{b}$ decay channels and the double Higgs boson analyses in the $b\bar{b}b\bar{b}$, $b\bar{b}\tau^+\tau^-$ and $b\bar{b}\gamma\gamma$ decay channels, using data collected at $\sqrt{s}$ = 13 TeV with the ATLAS detector at the LHC. The data used in these analyses correspond to an integrated luminosity of up to 79.8 fb^{-1} for single Higgs boson analyses and up to 36.1 fb^{-1} for the double Higgs boson analyses. With the assumption that new physics affects only the Higgs boson self-coupling (λ_{HHH}), values outside the interval $-2.3 < \lambda_{HHH}/\lambda_{HHH}^{SM} < 10.3$ are excluded at 95% confidence level. Results with less stringent assumptions are also provided, introducing additional coupling modifiers for the Higgs boson interactions with the other Standard Model particles.

40th International Conference on High Energy physics - ICHEP2020
July 28 - August 6, 2020
Prague, Czech Republic (virtual meeting)

*Speaker

PoS(ICHEP2020)104

ATL-PHYS-PROC-2020-114
03 December 2020

1. Introduction and input measurements

Measuring the strength of the trilinear self-coupling λ is important to describe the shape of the Higgs boson potential. So far the properties of the Higgs boson self-coupling are largely unconstrained at the LHC.

The non-resonant HH production processes provide a unique chance to probe $\kappa_\lambda = \lambda_{HHH}/\lambda_{HHH}^{SM}$ with direct measurements [1]. Single Higgs processes do not depend on λ_{HHH} at LO, while its contributions need to be considered for the complete NLO EW corrections via Higgs boson self energy loop corrections and via additional Feynman diagrams [2]. An indirect constraint on λ_{HHH} can be extracted from single Higgs boson production and decay process corrections.

Combining single-Higgs and double-Higgs together can maximize the sensitivity to constrain κ_λ. The results are obtained by combining the single Higgs boson analyses targeting the $\gamma\gamma$, ZZ^*, WW^*, $\tau^+\tau^-$ and $b\bar{b}$ decay channels and the double Higgs boson analyses in the $b\bar{b}b\bar{b}$, $b\bar{b}\tau^+\tau^-$ and $b\bar{b}\gamma\gamma$ decay channels, using data collected by the ATLAS experiment [3] in 2015, 2016 and 2017 from LHC 13 TeV pp collisions [4]. The data used in these analyses correspond to an integrated luminosity of up to 79.8 fb^{-1} for single Higgs boson analyses and up to 36.1 fb^{-1} for the double Higgs boson analyses.

2. Results

In the κ_λ-only model new physics is expected to only appear as a modification of the Higgs boson self-coupling. The combined result is [4]:

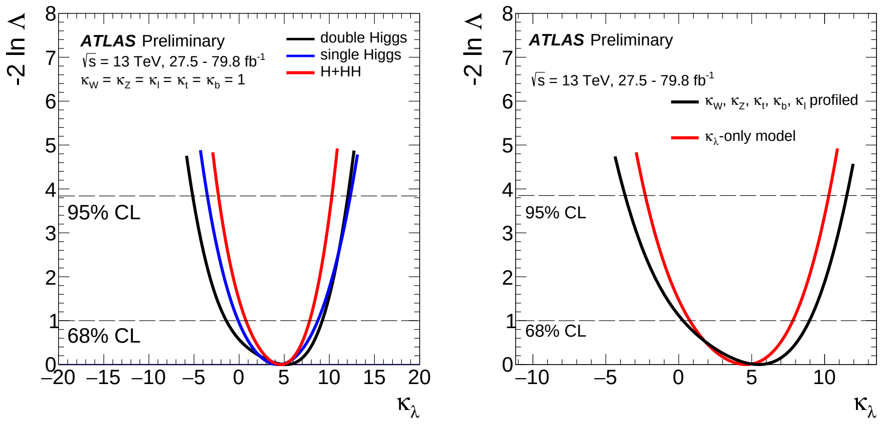
$$\kappa_\lambda = 4.6^{+3.2}_{-3.8} = 4.6^{+2.9}_{-3.5}(\text{stat.})^{+1.2}_{-1.2}(\text{exp.})^{+0.7}_{-0.5}(\text{sig. th.})^{+0.6}_{-1.0}(\text{bkg. th.}) \tag{1}$$

The value of $-2\ln\Lambda$ is shown as a function of κ_λ in Figure 1 (a). The observed (expected) 95% confidence level (CL) interval constraint on κ_λ is [−2.3, 10.3] ([−5.1, 11.2]). With only single Higgs analyses, the observed (expected) 95% CL interval constraint on κ_λ is [−3.2, 11.9] ([−6.2, 14.4]) [2], while with only double Higgs analyses, the observed (expected) 95% CL interval constraint is [−5.0, 12.0] ([−5.8, 12.0]) [1]. The sensitivity from single Higgs and double Higgs is similar. The combination can better constrain κ_λ (~ 20% improvement in 95% CL interval with respect to single Higgs or double Higgs analyses alone). With the present analysis statistics, double Higgs (ggF) production is the most sensitive channel among all Higgs production processes, followed by ggF single-Higgs production. $HH \to b\bar{b}\gamma\gamma$ and $HH \to b\bar{b}\tau^+\tau^-$ decays give the largest contributions in constraining κ_λ for all decay channels, followed by $H \to \gamma\gamma$ [4].

For a more model-independent measurement, a likelihood fit is performed to constrain simultaneously κ_λ, κ_W, κ_Z, κ_t, κ_b and κ_l. Figure 1 (b) shows the value of $-2\ln\Lambda$ as a function of κ_λ with κ_W, κ_Z, κ_t, κ_b, κ_l profiled [4]. Only the single-Higgs and double-Higgs combination can give enough sensitivity to exploit this generic model.

3. Conclusion

The Higgs boson self-coupling modifier $\kappa_\lambda = \lambda_{HHH}/\lambda_{HHH}^{SM}$ has been constrained with a combination of single-Higgs analyses using data collected at $\sqrt{s} = 13$ TeV with an integrated



(a) **(b)**

Figure 1: (a) Value of $-2\ln\Lambda$ as a function of κ_λ in the κ_λ-only model. (b) Value of $-2\ln\Lambda$ as a function of κ_λ with κ_W, κ_Z, κ_t, κ_b, κ_l profiled [4]. The curves are compared to the κ_λ-only model. The intersections of the dashed horizontal lines, corresponding to $-2\ln\Lambda = 1$ and $-2\ln\Lambda = 3.84$, with the profile likelihood curve are used to define the $\pm 1\sigma$ uncertainty on κ_λ and the 95% CL, respectively.

luminosity of up to 79.8 fb^{-1} and double-Higgs analyses with an integrated luminosity of up to 36.1 fb^{-1} with the ATLAS detector at the LHC. Under the assumption that new physics affects only the Higgs boson self-coupling, the best fit value of the coupling modifier is $\kappa_\lambda = 4.6^{+3.2}_{-3.8}$, excluding values outside the interval $-2.3 < \kappa_\lambda < 10.3$ at 95% CL. This constitutes a significant improvement on the constraints on κ_λ obtained from single-Higgs and double-Higgs analyses alone [1, 2]. A more model-independent parameterisation has also been considered, including coupling modifiers for the Higgs boson self-coupling, the up- and down-type quarks, leptons and for the W and Z bosons. In this more generic study the self-coupling modifier has been constrained at the 95% CL value to the interval $-3.7 < \kappa_\lambda < 11.5$. All other coupling modifiers are compatible with the SM predictions.

References

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