PROCEEDINGS OF SCIENCE

Parameterization of the Higgs boson STXS bins for the measurement of its self-coupling

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Higgs pair production processes provide the direct probe to the Higgs boson self-coupling (λ_3). However, as well known such a processes have a small production cross section. It is also known that single Higgs processes indirectly depends on λ_3, thus an alternative method to measure the λ_3 is considering λ_3-dependent next-to-leading-order (NLO) electroweak (EW) corrections in single Higgs processes. The magnitude of these corrections are encoded by some process and kinematic-dependent coefficients named as C_1. In the following, an overview of the determination and parametrization of the C_1 coefficients in Simplified Template Cross Sections (STXS) bins performed by ATLAS and CMS is shown in connection to the latest H+HH combination results with full Run 2 dataset.

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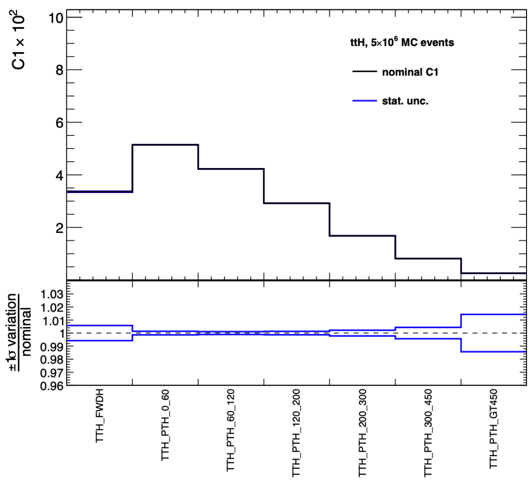
1. Introduction

Double Higgs (HH) searches provide direct access to probe the Higgs boson self-coupling (λ_3). However, as well known such processes have a small production cross section as $31.1^{+6.7\%}_{-23.2\%}$ fb for the Gluon-gluon fusion (ggF) and $1.73 \pm 2.1\%$ fb for the Vector boson fusion (VBF) processes. Alternatively, single Higgs (H) processes are sensitive to λ_3 through NLO EW corrections. An overview on the determination of C_1 coefficients for the single H cross sections parameterization as a function of the κ_λ[1] in the STXS 1.2 regions is described. Such parameterization facilitates the single H cross sections combination with the HH measurements which provides stringent constraints on the κ_λ.

2. Recipe for C_1 coefficients determination

The C_1 coefficients are computed differentially in the STXS 1.2 regions for the $H(jj)$, $W(l\nu)H$, $Z(ll)H$ and $t\bar{t}H$ (Figure 1) processes. The methodology detailed in [1] is briefly summarized in the following:

- About 5×10^6 events are generated for each process using MadGraph5_aMC@NLO (v 2.5.5) using PDF set PDF4LHC15_nlo_mc;
- For each event, the weight representing LO cross section (w_{LO}) and the weight corrected by κ_λ-effects are computed (w_{NLO}) [2];
- Events are further classified in STXS 1.2 bins using Rivet toolkit routine. The C_1 coefficients in a given STXS 1.2 bin is computed as: $C_1^i = \sum_j w^j_{\text{NLO}}/w^j_{\text{LO}}$, where the sum runs over all the events in $i-$th STXS bin.



(a)

Figure 1: The (a) C_1 coefficients for the $t\bar{t}H$ in the STXS 1.2 bins are shown [1].

[1] It is a common practice to define the κ_λ as the ratio between the λ_3 with respect to its SM prediction (λ_{SM}).

3. κ_λ constraints from the single Higgs and double Higgs combination

In order to improve the constraining on κ_λ, the following input analysis from single H channels as $H \to \gamma\gamma$ (all production modes), $H \to ZZ^* \to 4l$ (all production modes), $H \to \tau\tau$ (all production modes), $H \to WW \to e\nu\mu\nu$ (ggF and VBF), $H \to b\bar{b}$ (VBF, VH and $t\bar{t}H$) parameterized in STXS bins were combined with the three most sensitive HH channels as $HH \to b\bar{b}\gamma\gamma$, $HH \to b\bar{b}\tau\tau$ and $HH \to b\bar{b}b\bar{b}$ [3]. The profile likelihood ratio ($-2\ln\Lambda$) as a function of κ_λ is shown in Figure 2 for different models: (a) Constraining on κ_λ from the single H combination only as $-4.0 < \kappa_\lambda < 10.3$ at 95% CL; (b) $-0.6 < \kappa_\lambda < 6.6$ at 95% CL from the double Higgs combination only; (c) $-0.4 < \kappa_\lambda < 6.3$ at 95% CL from the single H and HH combination which provides the most stringent constraints (in the fit all other coupling modifiers are fixed to unity); (d) $-1.4 < \kappa_\lambda < 6.1$ at 95% CL for the generic model where besides the κ_λ, the κ_t, κ_b, κ_V and κ_τ are also simultaneously floated in the fit. The result for this model still show strong constraint on κ_λ.

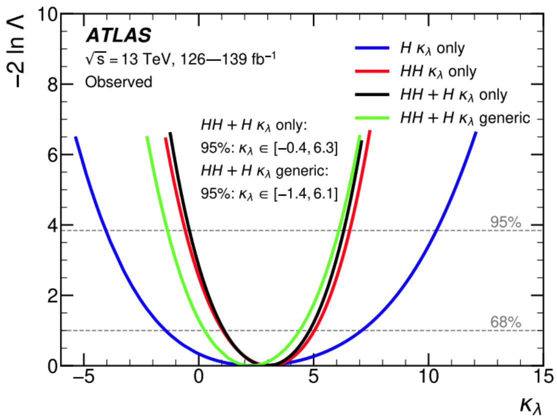


Figure 2: Observed values of the test statistic ($-2\ln\Lambda$) as a function of the κ_λ parameter for the single Higgs (blue) and HH (red) input analyses and their statistical combination (black) (fixing all other coupling modifiers to unity). The result for the generic model where κ_t, κ_b, κ_V and κ_τ are also simultaneously floated in the fit is also shown (green curve). The observed best-fit value of κ_λ for the generic model is shifted slightly relative to the other cases because of its correlation with the best-fit values of the κ_b, κ_t and κ_τ parameters, which are slightly below, but compatible with unity [3].

4. Summary

The recipe for the parameterization of the single H cross sections with respect to the SM prediction depending on the κ_λ in the STXS 1.2 regions is briefly described. Through this parameterization the differential information is extracted and further used for the combination with the HH searches. The combination between the single H and HH analyses is performed and the most strigent constrain to date on κ_λ is measured to be $-0.4 < \kappa_\lambda < 6.3$ at 95% CL.

References

[1] LHC Higgs Cross Section Working Group, *Modelling of the single-Higgs simplified template cross-sections (STXS 1.2) for the determination of the Higgs boson trilinear self-coupling*, Tech. Rep. LHCHWG-2022-002, CERN, Geneva (Mar, 2022).

[2] F. Maltoni, D. Pagani, A. Shivaji and X. Zhao, *Trilinear Higgs coupling determination via single-Higgs differential measurements at the LHC*, *Eur. Phys. J. C* **77** (2017) 887 [1709.08649].

[3] ATLAS collaboration, *Constraints on the Higgs boson self-coupling from single- and double-Higgs production with the ATLAS detector using pp collisions at s=13 TeV*, *Phys. Lett. B* **843** (2023) 137745 [2211.01216].

Signal channel	$\langle\epsilon\sigma\rangle^{95}_{\text{obs}}$[fb]	S^{95}_{obs}	S^{95}_{exp}	CL_B	$p(s=0)$ (Z)
nonres+VBF	0.07	9.7	$16.2^{+8.5}_{-5.2}$	0.08	0.13 (1.11)

Table 1: Left to right: 95% CL upper limits on the visible cross section ($\langle\epsilon\sigma\rangle^{95}_{\text{obs}}$) and on the number of signal events (S^{95}_{obs}). The third column (S^{95}_{exp}) shows the 95% CL upper limit on the number of signal events, given the expected number (and $\pm 1\sigma$ excursions on the expectation) of background events. The last two columns indicate the CL_B value, i.e. the confidence level observed for the background-only hypothesis, and the discovery p-value ($p(s=0)$).