Cubic and quartic Higgs self-coupling parametrizations of di-Higgs production at NLO

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Abstract

The self-interactions of the Higgs boson are of crucial importance for the large-scale structure of our universe. While the cubic self-coupling strength is beginning to be constrained by measurements of Higgs-boson pairs at the Large Hadron Collider, we here propose to extend this strategy to the quartic Higgs self-coupling. Thus, we present a novel parametrization of the inclusive gg → HH cross-section with respect to cubic and quartic Higgs self-couplings at next-to-leading order (NLO). We used POWHEG-BOX simulations of Higgs boson pair production in gluon-gluon fusion (ggHH) to achieve these results. We include parametrizations for 13 TeV, 13.6 TeV, and 14 TeV center-of-mass energies to align with LHC Run 3 energies. [1]

Background & Methods

1. Create package to introduce quartic self-coupling dependence to gluon-gluon fusion.
2. Create system to run POWHEG-BOX simulations in parallel that vary cubic (κ_3) and quartic (κ_4) self-coupling strengths at both LO and NLO and at different center-of-mass energies.
3. Run 7-point QCD scale variations to determine uncertainty bands of results.
4. Compare results with existing theoretical cubic self-coupling parametrizations of signal strength.

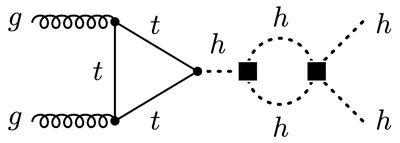

Figure 1. Feynmann diagram of cubic and quartic Higgs self-coupling that gives rise to gg → hh production (indicated by black squares) [2].

Results

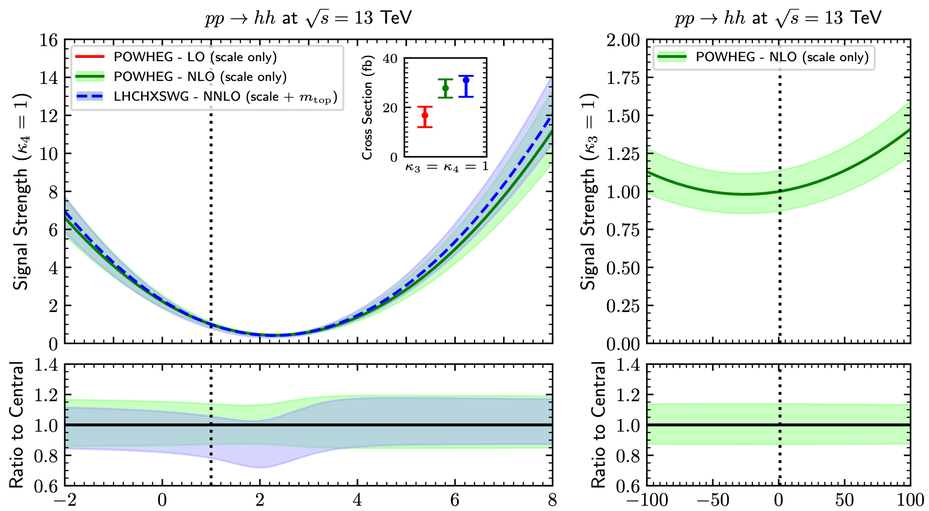

Figure 2. Signal strength as a function of κ_3 for $\kappa_4 = 1$ (left panel) and as a function of κ_4 for $\kappa_3 = 1$ (right panel) at NLO (green, solid). In the left panel, we display the recommendation of the Higgs cross-section working group for the HH cross-section as a function of κ_3 [3]. The Standard Model cross-sections are displayed in the inset (including the LO result). The shaded uncertainty bands correspond to the 7-point QCD scale variation (the Higgs cross-section working group recommendation includes top-mass uncertainty).

The inclusive cross-sections and QCD bounds for all energies are included in the full paper.

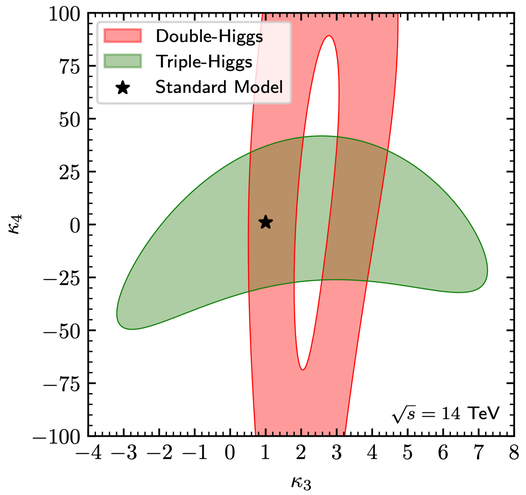

Figure 3. Hypothetical constraints in the κ_3 – κ_4 plane arising from inclusive double- (red) and triple- (green) Higgs production for HL-LHC at 14 TeV. The constraints are obtained assuming a 50% uncertainty on the signal strength for double-Higgs production and an upper limit of 20 times the Standard Model value for triple-Higgs production.

Conclusions

- We presented cubic and quartic self-coupling parametrizations of di-Higgs production at the LHC and the HL-LHC.
- Di-Higgs production provides complementary constraints on quartic self-coupling.
- We implemented and publicly released the ggHH calculation in the POWHEG-BOX framework [4].

$$\sigma(pp \to hh)^{\text{central}}_{14\,\text{TeV}} = 32.9\,\text{fb} \times [1 - 0.867(\Delta\kappa_3) + 1.48 \cdot 10^{-3}(\Delta\kappa_4) + 0.329(\Delta\kappa_3)^2 + 7.80 \cdot 10^{-4}(\Delta\kappa_3\Delta\kappa_4) + 2.73 \cdot 10^{-5}(\Delta\kappa_4)^2 - 1.57 \cdot 10^{-3}(\Delta\kappa_3)^2(\Delta\kappa_4) - 1.90 \cdot 10^{-5}(\Delta\kappa_3)(\Delta\kappa_4)^2 + 9.74 \cdot 10^{-6}(\Delta\kappa_3)^2(\Delta\kappa_4)^2]$$

Equation 1. Cross-section parametrization for 14 TeV HL-LHC with both κ_3 and κ_4 dependence.

Future Directions

We aim to conduct individual event simulations to parametrize differential (instead of inclusive) cross-section, which is used within ATLAS di-Higgs analyses.

References

[1] W. Bizoń, U. Haisch, L. Rottoli, et al. Addendum to: Constraints on the quartic Higgs self-coupling from double-Higgs production at future hadron colliders, JHEP 02 (2024) 170 [arXiv:2402.03463].
[2] W. Bizoń, U. Haisch and L. Rottoli, Constraints on the quartic Higgs self-coupling from double-Higgs production at future hadron colliders, JHEP 10 (2019) 267 [arXiv:1810.04665].
[3] M. Grazzini et al., Higgs boson pair production at NNLO with top quark mass effects, JHEP 05 (2018) 059 [arXiv:1803.02463]
[4] https://powhegbox.mib.infn.it.