Higgs Self Couplings: Measurements at Future proton-proton Colliders

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The Higgs trilinear and quartic self-couplings are directly related to the shape of the Higgs potential; measuring them with precision is extremely important, as they provide invaluable information on the electroweak symmetry breaking and the electroweak phase transition. The measurements of the Higgs self-couplings could also help probe new physics beyond the Standard Model (BSM), as large deviations from the Standard Model (SM) predictions typically occur.

The trilinear self-coupling can be extracted from the measurement of non-resonant Higgs boson pair (HH) production [1-2]. However, the NNLO cross section for double Higgs production at the LHC, dominantly from gluon-gluon fusion process, is only around 31 fb [3] at 13TeV, making the observation of double-Higgs production very challenging.

The CMS and ATLAS collaborations have been studying di-Higgs production to explore the Higgs trilinear coupling parameter λ_{HHH} and have published upper limits on the double Higgs production cross section through gluon-gluon fusion and different decay channels; among these channels, the most sensitive ones are bbγγ [4], bbττ (μτ, eτ, $\tau_h\tau_h$) [5], and bbbb[6]. A combination of the results in the various decay channels was published with data collected in 2016 [7] while new results from the full Run 2 data analysis are expected by the end of 2020.

While a measurement of the SM self-coupling is not feasible with the data collected during LHC Run 2 in Run 3, combining the ATLAS and CMS results of the full HL-LHC data set is expected to provide a 4σ (or greater) measurement of double Higgs production, and the modification of the self-coupling with respect to the SM prediction, $k_\lambda = \lambda_{3H\ Obs} / \lambda_{3H\ SM}$, is expected to be constrained to $0.1 < k_\lambda < 2.3$ at 95% confidence level (CL).

As for the measurements at the proposed future colliders, studies and projections show that λ_{HHH} can be measured to 15% precision at the HE-LHC (27 TeV) [8], and 5% at FCC-hh (100 TeV) [9]. If further improvements are possible at HE-LHC, this would be exciting. We intend to perform double Higgs production studies in the most sensitive decay channels bbγγ, bbττ, bbbb for several future colliders options: the HL-LHC at 14 TeV, a proton-proton machine at 28 TeV, 40 TeV, and at 100 TeV.

The double Higgs production via Vector Boson Fusion (VBF) has cross section more than an order of magnitude smaller than the gluon fusion one, but it features a distinct signature of two forward jets along with the di-Higgs system; the jets are characterized by a large invariant dijet mass and a large separation in pseudorapidity. A study of the VBF process provides access to hhVV quartic coupling with very good precision and we plan to explore this.

The studies will be carried out either through extrapolations from existing Run 2 results and/or using parametric simulations of the expected detector performance, luminosity, and pileup scenarios; the latter option will be based on the DELPHES [10] fast simulation software. Several assumptions have to be made to model the systematic uncertainties from theoretical and experimental sources. The project will take in consideration the various BSM models that would affect the SM HHH coupling. This survey will allow to identify the kinematic properties that characterize the specific models and use these inputs to maximize the analysis discrimination power.

The event selection will make use of multivariate analysis with Boosted Decision Trees (BDT) and Deep Neural Networks (DNN) exploiting the full kinematic information of the event; photon reconstruction, b tagging, and τ tagging will be the key elements to define the object selection. The inclusion of the track timing information will provide additional handles for signal to background separation.

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