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Higgs Self Couplings Measurements at Future proton-proton Colliders

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The Higgs boson 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. In this paper, we perform a detailed analysis of double Higgs boson production, through the gluon-gluon fusion process, in the most promising decay channels $b\bar{b}\gamma\gamma$, $b\bar{b}\tau\tau$, and $b\bar{b}b\bar{b}$ for several future colliders: the HL-LHC at 14 TeV and the FCC-hh at 100 TeV, assuming respectively 3 ab^{-1} and 30 ab^{-1} of integrated luminosity. In the HL-LHC scenario, we expect an upper limit on the di-Higgs cross section production of $0.76 \times \sigma_{\mathrm{SM}}$ at 95% confidence level, corresponding to a significance of 2.8 σ. In the FCC-hh scenario, depending on the assumed detector performance and systematic uncertainties, we expect that the Higgs self-coupling will be measured with a precision in the range 4.8-8.5% at 95% confidence level.

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[*] Speaker

1. Physics Motivation

The study of the Higgs boson pair production (HH) is one of the main goals of the scientific program at future colliders. It offers a direct experimental access to the Higgs boson trilinear self coupling and hence to the structure of the scalar potential itself. The di-Higgs production has a tiny cross section of 37 fb at 14 TeV in SM, with NNLO corrections [1][2], making its search arduous.

In order to access experimentally the HH phase space, it is essential to find a trade-off between high branching ratio and signal purity. For this study, three different final states are considered: $b\bar{b}\gamma\gamma$, $b\bar{b}\tau\tau$, $b\bar{b}b\bar{b}$. The $b\bar{b}\gamma\gamma$ final state has the highest purity, but suffers from a very low branching ratio; $b\bar{b}\tau\tau$ has the second highest branching ratio, is easy to trigger on due to the presence of leptons, and has a relatively low background; $b\bar{b}b\bar{b}$ has the highest branching ratio but suffers from high QCD- and tt-induced background.

2. Event Generation, Detector Simulation and Data Analysis

The signal and background processes in proton-proton (pp) collisions at 14 and 100 TeV are modelled using Monte Carlo (MC) event generators; the hadronisation and fragmentation effects are handled by using the PYTHIA8 [3] program. Signal processes from gluon-gluon fusion (ggF) HH production are simulated at next-to-leading order (NLO) with POWHEG 2.0 [4–6]. All the simulated samples are processed with the DELPHES [9] fast simulation program to model the detector response and performances [10][11]. Simulation accounts also for pileup contributions by overlaying an average of 200 (1000) minimum bias interaction events simulated with PYTHIA8 at center-of-mass energies of 14 (100) TeV. The data analysis for the three aforementioned double Higgs decay channels has been performed by using the Bamboo framework [12].

3. Results

The results obtained in each of the three decay channels, described in [13], are combined together assuming the SM branching fractions for HH decays to the studied final states. The integrated luminosity considered is: 3 ab^{-1} for HL-LHC at 14 TeV and 30 ab^{-1} for FCC-hh at 100 TeV.

At 14 TeV, a scenario with only statistical uncertainties (stat) and one statistical plus systematic (stat + sys) [13] are explored. At 100 TeV, a statistical only, a *14 TeV like* stat+sys (scenario 1) and an *optimistic* scenario (scenario 0) are explored. The scenario 0 supposes 0.5% uncertainty on luminosity measurement, 1%-2% on photon/b-tagging/lepton/tau efficiency, 1% on theoretical uncertainties. The analyses of the three decay channels are designed to be orthogonal thanks to the mutually exclusive object selection used for each channel. Different machine learning methods are used to improve the sensitivity. Systematic uncertainties on the theoretical assumptions or associated to the same object, such as b tagging efficiency, are treated as correlated, while all the others are left uncorrelated.

The upper limit on the signal strength for the HH combination at 14 TeV is 0.76 corresponding to a significance of 2.80. Results as a function of κ_λ are shown in Figure 2. Prospects for the measurement of the κ_λ at 14 TeV are shown for each channel and for the combination in Figure 2.

The expected confidence interval of this coupling is expected to be in the ranges [0.46, 1.73] at 68% CL and [-0.02, 3.05] at 95% CL.

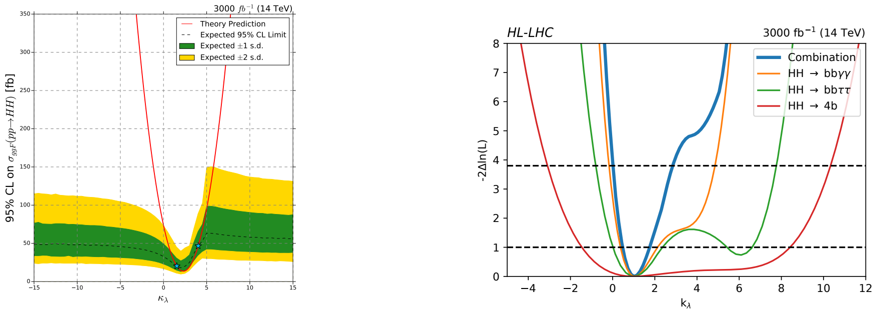

Figure 1: (Left) Expected upper limit at the 95% CL on the HH production cross section as a function of κ_λ with 1σ and 2σ bands. (Right) Expected likelihood scan as a function of κ_λ.

At 100 TeV, the combined expected precision on the signal strength at 30 ab^{-1} is 2-3.6% at 68% and 4-8% at 95%, depending on the systematic scenario considered [13]. The precision on the measurement of the Higgs self coupling assuming the presence of a HH signal with the same properties of the SM, is 2.4-3.9% at 68% and 4.8-8.5% at 95% (Figure 2). The precision on the signal strength and on the self coupling is also measured as a function of the luminosity, as reported in Figure 2.

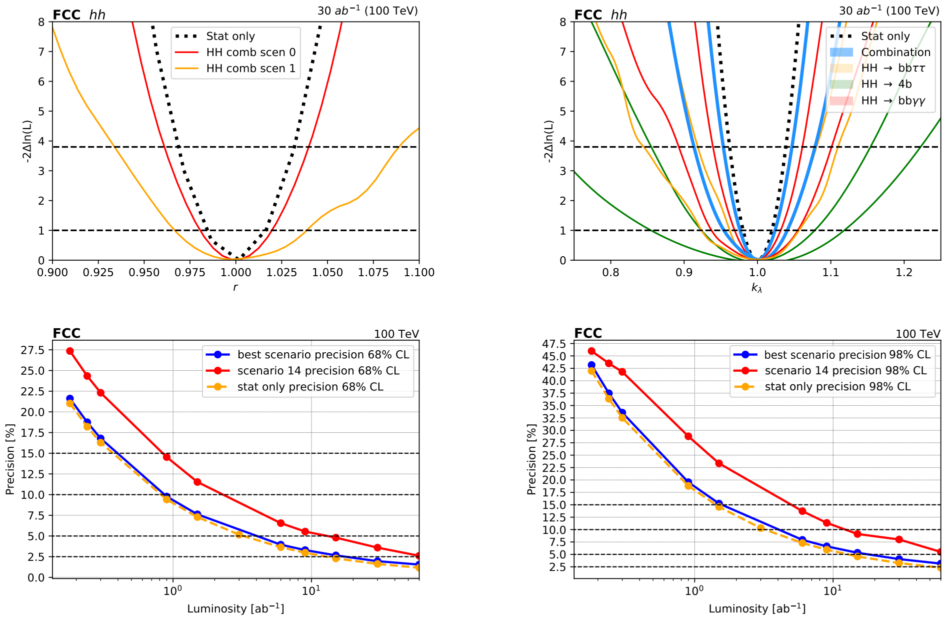

Figure 2: (Top-Left) Precision on the determination of the signal strength (Top-Right) Precision on the determination of the κ_λ. (Bottom-Left) Precision on the determination of the signal strength as a function of the luminosity at 68% CL (Bottom-Right) Precision on the determination of the signal strength as a function of the luminosity at 95% CL

References

[1] WG, L.H.X.: *Handbook of lhc higgs cross sections: 4. deciphering the nature of the higgs sector 2 (2017)*

[2] Micco, B.D., Gouzevitch, M., Mazzitelli, J., Vernieri, C.: *Higgs boson potential at colliders: Status and perspectives. Reviews in Physics 5*, 100045 (2020), https://www.sciencedirect.com/science/article/pii/ S2405428320300083

[3] Sjöstrand, T., Mrenna, S., Skands, P. *A brief introduction to pythia8.1*. Computer Physics Communications 178(11), 852–867 (2008)

[4] Alioli, S., Nason, P., Oleari, C., Re, E.: *NLO vector-boson production matched with shower in POWHEG*. Journal of High Energy Physics 2008(07), 060–060 (jul 2008), https://doi.org/10.1088/1126-6708/2008/07/060

[5] Nason, P.: *A new method for combining NLO QCD with shower monte carlo algorithms*. Journal of High Energy Physics 2004(11), 040–040 (nov 2004), https://doi.org/10.1088/1126-6708/2004/11/040

[6] Frixione, S., Nason, P., Oleari, C.: *Matching NLO QCD computations with parton shower simulations: the POWHEG method*. Journal of High Energy Physics 2007(11), 070–070 (nov 2007), https://doi.org/10.1088/ 1126-6708/2007/11/070 v

[7] Heinrich, G., Jones, S.P., Kerner, M., Luisoni, G., Scyboz, L.: *Probing the trilinear higgs boson coupling in di- higgs production at nlo qcd including parton shower effects*. Journal of High Energy Physics 2019(6) (Jun 2019), http://dx.doi.org/10.1007/JHEP06(2019)066

[8] Grazzini, M., Heinrich, G., Jones, S., Kallweit, S., Kerner, M., Lindert, J.M., Mazzitelli, J.: *Higgs boson pair production at nnlo with top quark mass effects*. Journal of High Energy Physics 2018(5) (May 2018), http://dx. doi.org/10.1007/JHEP05(2018)059

[9] De Favereau, J., Delaere, C., Demin, P., Giammanco, A., Lemaitre, V., Mertens, A., Selvaggi, M.: *Delphes 3: a modular framework for fast simulation of a generic collider experiment*. Journal of High Energy Physics 2014(2), 1–26 (2014)

[10] *The Phase-2 Upgrade of the CMS Tracker. Tech. rep.*, CERN, Geneva (Jun 2017), https://cds.cern.ch/record/2272264

[11] Abada, A., Abbrescia, M., AbdusSalam, S., et al: *FCC-hh: The Hadron Collider. Tech. rep.*, https://doi.org/10.1140/epjst/e2019-900087-0

[12] David, P.: *Readable and efficient HEP data analysis with bamboo*. EPJ Web Conf. 251, 03052 (2021)

[13] Taliercio, A., Mastrapasqua, P., Caputo, C., Vischia, P., De Filippis, N. and Bhat, P.: *Higgs Self Couplings Measurements at Future proton-proton Colliders: a Snowmass White Paper*. 10.48550/ARXIV.2203.08042

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