Letter of Interest: Higgs boson coupling measurements to charm quarks at FCC-ee

Aram Apyan,[a] **Matthew Baldwin,**[b] **Franco Bedeschi,**[c] **Gregorio Bernardi,**[d] **Alain Blondel,**[d] **Loukas Gouskos,**[e] **Patrick Janot,**[e] **Markus Klute,**[b] **Giovanni Marchiori,**[d] **and Michele Selvaggi**[e]

[a] *Fermilab, USA*
[b] *Massachusetts Institute of Technology, USA*
[c] *INFN Pisa, Italy*
[d] *LPNHE-Paris, CRNS/IN2P3, France*
[e] *CERN, Switzerland*

Abstract: The Higgs boson is expected to decay with a branching fraction of about 3% to $c\bar{c}$. The decay signature will be extremely difficult to isolate and measure at the LHC, but is directly accessible at FCC-ee if an efficient c-tagging algorithm, able to disentangle $c\bar{c}$ decays from other copious hadronic Higgs boson decays ($b\bar{b}$ and gg, and to a lesser extent, ZZ* and WW*) with high purity, can be designed. An ideal (100% efficient and 100% pure) tagging algorithm would yield a measurement of $\sigma_{\mathrm{ZH}} \times \mathrm{BR}(\mathrm{H} \to c\bar{c})$ with a precision better than 1%. Starting from the related experience developed at LHC and other e^+e^- collider projects, and with the help of the latest machine-learning technologies, such an algorithm will be developed, first with fast simulation, and then in the full context of the constraints from the interaction region and detector layout. The impact of the interaction-region and detector design (beam pipe radius, vertexing, vertex mass determination, tracker material, ...) on the precision $\sigma_{\mathrm{ZH}} \times \mathrm{BR}(\mathrm{H} \to c\bar{c})$ measurement will be studied. As a by-product, similar studies for the $\mathrm{H} \to b\bar{b}$ and $\mathrm{H} \to gg$ decays will be conducted as well. The need for calibration data at the Z pole will be estimated (frequency, number of events).

Contents

The FCC-ee, a lepton collider with center-of-mass collision energies between 90 and 365 GeV, is proposed to address key open questions of modern physics. The precision instrument is designed for the in-depth exploration of nature at the smallest scales, optimised to study the Z, W, Higgs and top particles with high precision, with samples of 5×10^{12} Z bosons, 10^8 W pairs, 10^6 Higgs bosons and 10^6 top quark pairs. FCC-ee offers unprecedented sensitivity to new physics, either via the production of new particles or in form of deviations from the Standard Model. The clean experimental conditions at lepton colliders allow for precision measurements of the known particles with the highest precision and for exploring the unknown [1, 2].

As a proposed Higgs factory, the cornerstone of the FCC-ee physics program is the exploration of the Higgs boson at center-of-mass energies of 240 to 365 GeV. A direct and model-independent measurement of its coupling to the Z boson through the study of the Z boson recoil mass spectrum in $e^+e^- \to Z + X$ events at $\sqrt{s} = 240$ GeV. This measurement is unique to lepton colliders. The measurement of the $\mathrm{H} \to \mathrm{ZZ}$ process provides then sensitivity to the total Higgs boson width. Absolute values of the other Higgs boson couplings follow from measurements of different production and decay channels. The improvement over the projected HL-LHC results are significant for most Higgs boson couplings. The study of Higgs boson couplings to charm at the LHC is extremely difficult and will not reach sensitivity to probe the Higgs boson at the level predicted by the Standard Model. The access to Higgs boson couplings of the second generation quark sector is therefore a unique opportunity for lepton colliders. The clean environment, lower background rates, and detector and algorithms with efficient c-tagging performance at the FCC-ee enables to disentangle $\mathrm{c\bar{c}}$ decays from other copious hadronic Higgs boson decays in a simultaneous measurement, with $\mathrm{b\bar{b}}$ and gg being most challenging [3].

The roadmap of the proposed program of work is to establish the analysis benchmark, inform the detector design, and extend studies from fast to full simulation. The key achievement will be the development of efficient charm and b tagging algorithm using modern machine-learning technologies. Starting from the related experience developed at LHC and other $\mathrm{e^+e^-}$ collider projects, such an algorithm will be developed. Developments start with fast simulation (Delphes) and then move to the context of full simulation to study constraints from the interaction region and detector layout.

A new library that allows for the derivation of the full tracking covariance matrix given an arbitrary tracker geometry has recently been included in Delphes. The full tracking information, in particular the track transverse and longitudinal displacement will be passed as an input to a deep neural network in order to produce a nearly optimal c-tagging discriminator. Such a tool opens the possibility of designing a tracker layout that maximises the performance of c-jet identification and therefore the achievable precision on the charm Yukawa coupling at the FCC-ee.

References

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[2] N. Alipour Tehrani et al., *FCC-ee: Your Questions Answered*, in *CERN Council Open Symposium on the Update of European Strategy for Particle Physics* (A. Blondel and P. Janot, eds.), 6, 2019. 1906.02693.

[3] FCC collaboration, A. Abada et al., *FCC Physics Opportunities: Future Circular Collider Conceptual Design Report Volume 1*, *Eur. Phys. J. C* **79** (2019) 474.