PROCEEDINGS OF SCIENCE

Higgs measurements at the Future Circular Colliders

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After the Higgs boson discovery, precision measurements and searches for new phenomena in the Higgs sector are among the most important goals in particle physics. Experiments at the Future Circular Colliders (FCC) are ideal to study these questions. Electron-positron collisions (FCC-ee) up to an energy of 365 GeV provide the ultimate precision with studies of Higgs boson couplings, mass, total width and CP parameters, as well as searches for exotic and invisible decays. We conclude by noting the remarkable complementarity of the FCC-ee and FCC-hh colliders, which in combination offer the best possible overall study of the Higgs boson properties.

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1. Introduction

The discovery of the Higgs boson [1] in 2012 has dramatically changed the landscape of particle physics. Measuring the Higgs boson properties as well as searches for new phenomena in the Higgs sector are now one of the most important goals in particle physics. At HL-LHC [2] we will be able to measure the Higgs couplings to fermions and bosons with a precision of the order of 5-10%. In order to significantly improve these measurements new accelerator facilities will be needed. Several possibilities are being investigated and proposed: large circular leptonic colliders (100 km circumference), like the Future Circular Collider [3] (FCC) FCC-ee [4] and the Circular Electron Positron Collider (CEPC) [5], linear colliders, like the International Linear Collider [6] (ILC) and the Compact Linear Collider [7] (CLIC), and large proton-proton colliders, like the FCC-hh and the Super Proton Proton Collider (SPPC).

Circular lepton colliders can achieve higher luminosities but lower center-of-mass energies, while linear lepton colliders can reach higher energies but cannot really compete with circular colliders for luminosity at lower energies. This can be clearly seen in figure 1. The data taking programs of the circular colliders call for 5 ab^{-1} of integrated luminosity in 3 years of operation at $\sqrt{s}$=240 GeV for FCC-ee and 5 ab^{-1} in 7 years at $\sqrt{s}$=240 GeV for CEPC, while in the case of linear colliders ILC will collect 2 ab^{-1} of data in 15 years of operation at $\sqrt{s}$=250 GeV and CLIC will collect 0.5 ab^{-1} in 7 years of operation at $\sqrt{s}$=380 GeV. This demonstrates again the large advantage in terms of integrated luminosity of the circular lepton colliders. Moreover both FCC-ee and CEPC will run at the Z peak and at the WW production threshold. FCC-ee also plans to collect data at the $t\bar{t}$ peak, with an integrated luminosity of 1.5 ab^{-1}, making this machine the only one that can do extremely high precision measurements of all the electroweak sector.

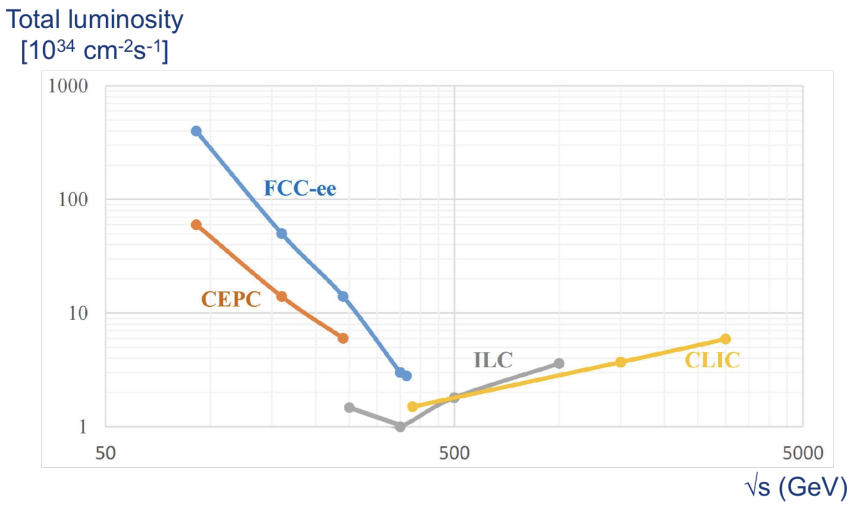

Figure 1: Maximum instantaneous luminosities of proposed future lepton colliders. On the horizontal axis is reported the center-of-mass energy, while on the vertical axis is instantaneous luminosity. At energies below $\sqrt{s}$=365 GeV circular colliders have a significant advantage over linear colliders.

PoS(ICHEP2018)685

2. Higgs boson measurements

At FCC-ee the Higgstrahlung process is the dominant production mode, in which the Higgs boson is produced accompanied by a real Z boson, $e^+e^- \rightarrow HZ^* \rightarrow HZ$, see figure 2.

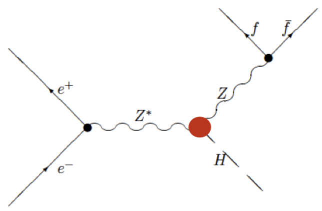

Figure 2: Higgstrahlung production process of a Higgs boson accompanied by a Z boson.

The cross-section of this process is maximal around 240-250 GeV. With 5 ab^{-1} collected at 240 GeV, FCC-ee will produce 1 million HZ events. With 1.5 ab^{-1} of data at 365 GeV FCC-ee this will add another 180000 HZ events. A characteristic of this process is that the events can be tagged using the Z decay products, independently of the Higgs decay. With FCC-ee a precision on the measurement of the HZ cross-section of 0.7% can be obtained. Combining the measurements at 240 GeV with the ones at 365 GeV, one obtains a precision on the width of the Higgs boson, $\delta\Gamma_H/\Gamma_H$, of 1.6%. By using the measured HZ cross-section and the total width one can then perform absolute measurements of the couplings of the Higgs bosons to all the SM particles in a model independent way. The relative precisions on the Higgs couplings, $\delta g_H/g_H$, obtained at FCC-ee are shown in Table 1. The precision on some couplings can be further improved using also the data collected at $\sqrt{s} = 365$ GeV. Using also the measurements performed at HL-LHC one can further constrain a few of the couplings, in particular $g_{H\mu\mu}$ and $g_{H\tau\tau}$. Several Higgs couplings will therefore be measured at FCC-ee with a sub-percent precision. This represents roughly an order of magnitude improvement compared to what will be achievable at HL-LHC.

Coupling	**FCC-ee 240 GeV (in %)**	**+FCC-ee at 365 GeV (in %)**	**+HL-LHC (in %)**
δg_{HZZ}	0.25	0.22	0.21
δg_{HWW}	1.3	0.47	0.44
δg_{Hbb}	1.4	0.68	0.58
δg_{Hcc}	1.8	1.23	1.20
δg_{Hgg}	1.7	1.03	0.83
$\delta g_{H\tau\tau}$	1.4	0.8	0.71
$\delta g_{H\mu\mu}$	9.6	8.6	3.4
$\delta g_{H\gamma\gamma}$	4.7	3.8	1.3
δg_{Htt}			3.3
$\delta\Gamma_H$	2.8	1.56	1.3

Table 1: Relative precision (in %) on the Higgs couplings, $\delta g_H/g_H$, to SM particles that can be obtained at FCC-ee. In the third column are reported the values obtained combining also the data taken with FCC-ee at $\sqrt{s}$=365 GeV, while on the last column are listed the values obtained combining also the results of HL-LHC.

A very peculiar characteristic of the Higgs boson is that it couples to itself. The very large datasets available at the FCC-ee will allow to obtain model-independent bounds from a global-fit on Higgs self-coupling κ_λ and the coupling to SM bosons c_Z. A precision of $\pm$40% on $\delta\kappa_\lambda$ and of $\pm$35% on c_Z can be obtained combining also the results from HL-LHC. There is also a very good synergy between FCC-ee and FCC-hh for measuring the Higgs self-coupling, because FCC-hh can measure the Higgs self-coupling directly. There are in fact two production processes that form a triple-Higgs vertex, see figure 3, but the two processes negatively interfere and hence the cross-section is very small.

Figure 3: Production processes of the triple-Higgs vertex at the FCC-hh.

However at FCC-hh with $\sqrt{s}$=100 TeV the cross-section increases by a factor of 40 compared to the HL-LHC and the integrated luminosity will be 10 times larger, 30 ab^{-1} instead of 3 ab^{-1}. The precise branching ratio measurements from FCC-ee will allow to measure δ_μ with a precision of 2-4% and δ_κ with a precision of about 5% at FCC-hh.

3. Conclusions

The circular colliders FCC-ee and CepC, will provide a much lager luminosity than the linear colliders ILC and CLIC. The sample of 1 million HZ event produced at FCC-ee will allow to measure the HZ cross-section with extreme precision and also provide a model-independent measurement of the Higgs total width. Most Higgs couplings to SM particles will be measured with sub-percent precision. By combining the data from FCC-ee and FCC-hh one can obtain a precision on the Higgs self-coupling of the order of 5%. FCC-ee and FCC-hh will therefore provide the best possible Higgs measurements of any new accelerator.

References

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