FCC-ee as Z, W and H factory

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Abstract

The Future Circular Collider integrated project foresees, as a first stage, a high-luminosity electron-positron collider (FCC-ee), to study with high precision the Z, W, and Higgs bosons, with samples of $5\cdot10^{12}$ Z bosons, 10^8 W pairs, and 10^6 Higgs bosons. Optionally, the FCC-ee could then be upgraded to higher energy for top quark production, before later being followed by a highest-energy hadron collider (FCC-hh) installed in the same tunnel. The FCC-ee should be designed with maximum energy-efficiency with regard to hardware, operational scenarios, and parameters. The beam parameters are limited by several, partly new effects, such as beamstrahlung in collision, a coherent beam-beam instability with large crossing angle, the available top-up injection rate, and instabilities related to the large ring circumference. Luminosity optimization must consider these effects along with numerous other constraints. The number of collision points is a further variable.

The search for new particles with extremely small couplings or for forbidden phenomena, in Z or Higgs boson decays in particular, could provide the first clues towards the understanding of some of the outstanding fundamental questions in particle physics [1]. An e^+e^- collider, like the FCC-ee [2], with high luminosities at centre-of-mass energies between ~90 and ~240 GeV, and upgradeable to ~365 GeV has a strong physics case in this respect, as it covers the Z pole, and the W-pair production threshold, and allows for copious Higgs boson production. Also profiting from an extremely precise energy calibration at the Z and W energies, such a device will improve precision electroweak and Higgs physics by orders of magnitude with respect to the present state of the art.

To provide relevant sensitivity to new physics, the FCC-ee must deliver integrated luminosities at centre-of-mass energies from around the Z pole to the Higgs production peak (and later, optionally, also above the top-pair threshold), such that the statistical precision of a complete set of electroweak and Higgs observables improves by one to two orders of magnitude. The data samples needed to achieve this goal correspond to:

1. An integrated luminosity of 100 ab^{-1} at the Z pole for the measurement of the effective weak mixing angle and for the search for and the study of rare Z decays. These data are also important for the determination of the Z mass and of the strong coupling constant at the Z mass scale.
2. An integrated luminosity of 30 ab^{-1} at $\sqrt{s} \sim 88$ and at 94 GeV for the determination of the Z total width; these data are also optimal for the direct measurement of the electro-magnetic coupling constant at the Z mass scale.
3. An integrated luminosity of 10 ab^{-1} around the WW threshold, for the measurement of the W mass and width, evenly shared between $\sqrt{s} \sim 157.5$ and 162.5 GeV. These data also provide the number of light neutrino species and an independent measurement of the strong coupling constant.
4. An integrated luminosity of 5 ab^{-1} at $\sqrt{s} = 240$ GeV for an absolute measurement of the Higgs boson couplings and decay width, that breaks the model-dependence inherent to hadron colliders.

Issues requiring further studies and optimization include the following:

1. Design for maximum energy efficiency.
2. Attainable vertical emittance in presence of various errors and with colliding beams, and further luminosity optimization.
3. Complete impedance model, with an evaluation of transverse multibunch resistive-wall instability and single-bunch longitudinal microwave instability.
4. Ion and electron-cloud instabilities with mitigation measures.
5. Design and performance of a bunch-by-bunch feedback system.
6. Interplay of impedance and beam-beam effects.
7. Dynamic aperture optimization.
8. Design for different numbers of collision points.
9. Finalisation, integration and completion of beam optics, including tuning flexibility, injection and extraction systems.
10. Collimation / masking and machine protection strategy.
11. Specification of beam instrumentation and the required measurement precision/accuracy.
12. Optimization of the injector complex.

This list is certainly incomplete. Technical design contributions from the Snowmass and greater US community to these and other studies will be most welcome!

Looking forward, after 10-15 years of operation (or possibly 20 years, in case of an additional, dedicated monochromatized run for s-channel Higgs production), most of the FCC-ee infrastructure can be directly reused for a subsequent energy-frontier hadron collider (FCC-hh) [3], so that the FCC would serve the world-wide particle-physics community in a synergetic and cost-effective manner throughout the 21st century, as envisaged in the Future Circular Collider integrated project plan [4].

References

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