FCC-ee upgrade to top factory

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Abstract

After about ten years of operation at the Z, W and Higgs collision energies, from 90 to 240 GeV, the high-luminosity electron-positron collider (FCC-ee), could be upgraded to operate at and above the $t\bar{t}$ threshold. The higher energy loss per turn requires a substantial additional SRF system, consisting of 5-cell bulk Nb cavities operated at 2 K, while up to 240 GeV only 4-cell Nb/Cu cavities are used. The beams, at 365 GeV consisting of only a small number of bunches each, will also be made to share the RF cavities. Beam dynamics issue related to many bunches and high current are no longer an issue. The beam lifetime limitation from beamstrahlung becomes a concern, calling for an adequate off-momentum dynamic aperture. The higher critical energy of synchrotron radiation in the arcs, and especially in the interaction region raises other issues.

The completion of the FCC-ee precision physics programme [1,2,3] and searches for signs of new physics beyond the standard model require operation at the $t\bar{t}$ threshold. Running at 340 to 365 GeV allows an improved measurement of the Higgs width with relative precision of 1%, a measurement of the top quark mass to 20 MeV and of the top electroweak couplings to the per-cent level, and could offer a 3σ sensitivity to the trilinear Higgs self-coupling [4].

At 240 GeV the FCC-ee operates with a total of 4 GV RF voltage provided by 68 cryomodules, each containing four 400-MHz four-cell Nb/Cu cavities. The operation at the $t\bar{t}$ threshold requires an additional 6.9 GV RF voltage in the collider, and additional 8.9 GV in the booster, provided by 93 and 120 cryomodules, containing 800 MHz five-cell bulk Nb cavities. This major installation in, and reconfiguration of, the RF straights requires about one year without beam operation, to prepare for this high-energy running mode of the FCC-ee.

The physics goals call for the following integrated luminosities at the $t\bar{t}$ threshold:

1. An integrated luminosity of ~0.2 ab^{-1} in a 5-GeV-wide window around the top-pair threshold, typically shared among eight points from ~340 to ~350 GeV for the measurement of the top-quark mass and width.
2. An integrated luminosity of 1.5 ab^{-1} above the top-pair threshold, $\sqrt{s}$ ~ 365 GeV, optimal for the measurement of the top electroweak couplings. These data provide a twofold improvement of the Higgs boson width accuracy with respect to the 240 GeV data, and allow for the first 3 σ evidence of the Higgs self-coupling.

Issues requiring further studies and optimization include:

1. Interaction region optimization and shielding of the hard synchrotron radiation including radiation from the final quadrupoles.
2. Beam-tail collimation for background control.
3. Further off-momentum dynamic aperture optimisation to maximize beamstrahlung lifetime.
4. Operational scenarios supporting higher luminosity and shorter beam lifetimes with more frequent injections.
5. Single-bunch beam instabilities with highest bunch charge.
6. RF system changes for collider and booster, with associated modified optics configuration.
7. Maximum energy efficiency.
8. Machine protection and radioprotection.

This list certainly is quite incomplete and could be extended for and during Snowmass 2020 discussions. Relevant contributions from universities and laboratories are encouraged.

References

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