# *Accelerator Physics Exercises No. 1*

## *- Work to be handed in on 27 January 2022*

The aim of Hilary Term's work is to prepare a Student Design Project on the study of the Future Circular Collider electron-positron (*FCC-ee*) particle physics research facility.

The Student Design Project relates to a novel research infrastructure based on a highest-luminosity energy frontier electron-positron collider (*FCC-ee*) to address the open questions of modern particle physics. It will be a general instrument for the continued in-depth exploration of nature at the smallest scales, optimised to measure precisely the properties of the Higgs boson at the percent level, as well as the Z and W bosons, the top quark and the Higgs coupling to the Z at the per-mille level.

The Student Design Project will concentrate on the *FCC-ee* and the investigation of its various components, focusing on the general lay-out, the lattice design, the choice of magnet technology and magnet design, and the RF system for acceleration.

A description of the *FCC-ee* is available in the Conceptual Design Report (and references therein) under Tutorial 2 (Week 2) of this term at the course INDICO page at

https://indico.cern.ch/event/1101643/

Further information on the FCC is available at

https://fcc.web.cern.ch/Pages/default.aspx

https://fcc-cdr.web.cern.ch/

**Question 1.1 (Introduction)**

Imagine you are writing the introductory section of the *FCC-ee* Design Report. Describe clearly and in detail the following:

(a) The physics that can be addressed by the *FCC-ee* as well as by the FCC hadron-hadron (*FCC-hh)* and FCC hadron-electron (*FCC-he)* colliders. Elaborate by discussing some key physics channels.

(b) The *FCC-ee* performance requirements and overall configuration. Elaborate on the particle beam requirements for both the *FCC-hh* and *FCC-ee*. Compare the two particle beam options and elaborate the pros and cons of each.

(c) At the high energies of the *FCC-ee*, electrons emit significant synchrotron radiation. Revisiting the synchrotron radiation lectures, what is the typical photon energy emitted by the electrons and how much energy is lost per turn due to synchrotron radiation for each of the *FCC-ee* operating beam energies?

(d) Discuss the role of the Booster and top-up injection scheme for the *FCC-ee*.

(e) Discuss the advantages and disadvantages of the FCC-*ee* compared to a Muon Collider, a Linear Collider, namely the Compact Linear Collider (CLIC) and the International Linear Collider (ILC), and to the Circular Electron-Positron Collider (CEPC).

**Question 1.2 (The Lattice)**

a) Describe possibilities being considered for the *FCC-ee* injection complex.

b) Study the *FCC-ee* lattice presented by Katsunobu Oide under his presentation 'Status of the FCC-ee optics and next steps' available at

   https://indico.cern.ch/event/1085318/timetable/

   Create a MAD-X input file for a main arc cell and use it to calculate and plot the beam envelopes and optical functions.

c) Discuss the basic design choice for the *FCC-ee* lay-out with two experiments. Compare it to the new lay-out that allows four experiments. See Lecture 24 from last term and Tutorial 2 (Week 2) of this term at the course INDICO site.

For any clarification, please contact Prof. Emmanuel Tsesmelis (Emmanuel.Tsesmelis@cern.ch).

**Question 1.3 (The RF Cavities)**

Referring to the Conceptual Design Report and Lecture 24 from last term at the course INDICO site, elaborate on the following points for the *FCC-ee* RF system.

(a) Examine and present the main requirements of the RF system for the *FCC-ee* for the various operating beam energies. Discuss the reasoning behind the choice of a superconducting or a normal-conducting RF system.

(b) Discuss the various possible RF frequencies for the *FCC-ee* and the preferred choice of frequency for each operating beam energy. Can a single RF system be designed to meet the requirements for all energy cases? Discuss the advantages and disadvantages of this strategy.

(c) Using the *FCC-ee* machine parameters examined above, estimate the minimum required accelerating voltage that the RF system would have to provide for each operating scenario?

(d) Propose a superconducting cavity design for a 400 MHz RF frequency for operation at a beam energy of 45 GeV (at the Z resonance) and model it using Superfish (including tuning it to the correct frequency). Assuming an accelerating gradient of 5 MV/m, estimate how many cavities would be needed to provide the required accelerating voltage per turn. Estimate the total beamline space needed for the RF system. Present your cavity design, the main parameters and the field on axis. (Hint: Superfish examples are a good starting point).

For any clarification, please contact Dr. Ciprian Plostinar (ciprian.plostinar@ess.eu).

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