Accelerator Physics Exercises No. 1

- Work to be handed in on 30 January 2020

The aim of Hilary Term's work is to prepare a Student Design Project as part of the Rapid Cycling Synchrotron (*RCS*) for the fast acceleration of muons to the TeV-scale for injection into a *Muon Collider*.

Muon Colliders offer a great potential for high-energy physics in terms of precision physics measurements and as a particle discovery machine. They provide collisions of point-like particles at TeV-scale energies, since muons can be accelerated in a compact ring without limitation from synchrotron radiation.

However, the need for high luminosity faces technical challenges arising from the short muon lifetime at rest and the difficulty of producing large numbers of muons in bunches with small emittance. Addressing these challenges requires the development of innovative concepts and demanding technologies.

The Student Design Project will concentrate on the *RCS* and the investigation of this fast-ramping accelerator, 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 *Muon Collider* in general is available at:

https://map.fnal.gov/

and additional documentation is available at the course INDICO page at

https://indico.cern.ch/event/867138/

Question 1.1 (Introduction)

Imagine you are writing an introductory section of the Student Design Report. Describe clearly and in detail the following:

(a) The physics that can be addressed by a *Muon Collider* at both 3 TeV and 14 TeV centre-of-mass energies.

(b) The advantages and disadvantages of a *Muon Collider* compared to other lepton colliders, circular and linear electron-positron colliders, as well as hadron colliders.

(c) The main *Muon Collider* design considerations and parameters at centre-of-mass energies of 3 TeV and 14 TeV.

(d) The proton driver muon production scheme and the positron driver Low Emittance Muon Accelerator (LEMMA) scheme.

(e) The motivation for a multi-TeV *RCS* accelerator. Review the main machine design considerations and parameters for it to serve as an injector for a *Muon Collider* with centre-of-mass energies of 3 TeV and 14 TeV.

Question 1.2 (The Lattice)

Starting from an *RCS* reference design at 750 GeV given in the paper by Summers *et al.* in the INDICO page above discuss the following issues for a 1.5 TeV *RCS*.

(a) Scaling from the design of the *RCS* hybrid ring at 750 GeV, calculate the top magnetic field and length for the fixed-field superconducting magnets and the interleaved fast-ramping normal-conducting magnets. From this, calculate the minimum and maximum rigidity and propose a compact ring circumference. Calculate the 'filling factor' – the proportion of the circumference taken up by the bending magnets.

(b) Propose a modified 400 GeV Fermilab Main Ring FODO lattice to reach 1.5 TeV. Assume quadrupole magnets of 30 T/m gradient field.

(c) Create a MADX input file with one basic arc half-cell. Calculate the length of the half-cell consisting of half of two ramping quadrupoles, two fixed-field superconducting dipoles and three ramping dipoles. Use MADX to calculate and plot the periodic beta functions and dispersion in the half-cell.

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

Question 1.3 (The RF Cavities)

A superconducting RF system could be used for acceleration. The cavities could be installed either within a single straight section or distributed over several stations in the RCS.

(a) Discuss the main requirements of the RF system for the 1.5 TeV *RCS*, including considerations for the RF system within a single straight section or distributed over several stations.

(b) Using the *RCS* parameters examined above, estimate the number of turns needed to accelerate the muon beam from 400 GeV to 1.5 TeV within the muon lifetime. What would be the accelerating voltage that the RF system would be required to provide per turn?

(c) Propose a potential RF frequency (or frequencies) for the *RCS* and discuss your suggestion.

(d) Propose a cavity design for one of your suggested frequencies and model it using Superfish (including tuning it to the correct frequency). Present your findings and discuss your cavity choice. Assuming an accelerating gradient of 25 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. (Hint: The Superfish examples are a good starting point).

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