Università di Ferrara — Dipartimento di Fisica e Scienze della Terra
High Energy Physics Laboratory — Accelerator Physics Module

Final Report

Name: ______________________ Course/Year: ______________________

E-mail: ______________________ Date: ______________________

This report is part of the course evaluation. Students may work on it together. Each student should turn in his or her own handwritten copy as soon as possible and at least 3 weeks before the oral exam. The report consists of 4 parts: multiple-choice questions, definitions of terms, a problem, and a short essay.

Multiple-choice questions

Mark the answer that you think is closest to the correct answer.

An electron is moving with a relativistic factor $\gamma = 20$. Its momentum is

☐ 1 MeV/c ☐ 2 MeV/c ☐ 5 MeV/c ☐ 10 MeV/c ☐ 20 MeV/c

If a proton has a kinetic energy of 2 GeV, its magnetic rigidity is

☐ 1 $\mathrm{T \cdot m}$ ☐ 2 $\mathrm{T \cdot m}$ ☐ 6.7 $\mathrm{T \cdot m}$ ☐ 9.3 $\mathrm{T \cdot m}$ ☐ 20 $\mathrm{T \cdot m}$

A quadrupole magnet has aperture radius $R = 25$ mm and length $l = 15$ cm. Around each iron pole, $N = 40$ turns of conductor carrying current I are wound. What is the current I needed to focus particles with magnetic rigidity $(B\rho) = 0.5$ $\mathrm{T \cdot m}$ if the desired focal length is $f = 2$ m?

☐ 8 A ☐ 10 A ☐ 16 A ☐ 35 A ☐ 80 A

In a fixed-target experiment, if the target density is doubled while other parameters are left unchanged, then the luminosity

☐ is unchanged ☐ quadruples ☐ doubles ☐ halves ☐ is reduced to 1/4

In a detector with total efficiency $\varepsilon = 10\%$, the event rate is $R = 1$ kHz for events with a known cross section $\sigma = 1$ μb. The luminosity is

☐ 10^{32} $\mathrm{cm^{-2}s^{-1}}$ ☐ 10^{34} $\mathrm{cm^{-2}s^{-1}}$ ☐ 10^{36} $\mathrm{cm^{-2}s^{-1}}$ ☐ 10^{38} $\mathrm{cm^{-2}s^{-1}}$ ☐ 10^{40} $\mathrm{cm^{-2}s^{-1}}$

In a synchrotron, if the rf voltage is multiplied by 4, the synchrotron frequency for small-amplitude oscillations changes by a factor

☐ 4 ☐ 2 ☐ 1/2 ☐ 1/4 ☐ 1/8

In a synchrotron with slip factor η, as the amplitude of the synchrotron oscillations increases, the synchrotron tune

☐ increases ☐ doesn't change ☐ decreases ☐ increases if $\eta > 0$ ☐ decreases if $\eta > 0$

The horizontal profile of a Gaussian beam has a standard deviation of 6 mm at a location where the amplitude function is 6 m. The rms geometrical emittance of the beam is

☐ 0.1 μm ☐ 0.5 μm ☐ 1.0 μm ☐ 3.0 μm ☐ 6.0 μm

In a collider like the LHC (relativistic factor $\gamma = 6928$), the amplitude function at the interaction region is $\beta = 40$ cm and the normalized rms beam emittance is $\varepsilon = 2.75$ μm. The standard deviation of the transverse beam size at the interaction region is

☐ 1.3 μm ☐ 13 μm ☐ 1 mm ☐ 11 mm ☐ 1 m

Definitions

Define the following terms using less than 120 words each.

Luminosity

Transition energy

Problem

Consider Hill's equation $x'' + K \cdot x = 0$, describing the transverse displacement $x(s)$ of a particle in an accelerator, as a function of the longitudinal coordinate s, where $K(s)$ is a known function representing the distribution of normalized magnetic field gradients. Solutions are of the form $x(s) = \sqrt{\beta(s) \cdot \varepsilon} \cdot \cos[\psi(s) + \delta]$, where the constants ε and δ depend on the initial conditions, whereas the amplitude function $\beta(s)$ and phase $\psi(s)$ depend on the machine lattice.

(a) By substituting the general solution into Hill's equation, and by separately considering the resulting sine and cosine terms, derive two coupled differential equations for the amplitude function and phase.

(b) Find the relationship between $\beta(s)$ and $\psi(s)$ by showing that one of the differential equations derived in (a) is equivalent to the condition $\beta \cdot \psi' = C$, where C is an arbitrary constant. (In the Courant-Snyder parameterization, $C = 1$ is usually chosen.) What is the physical interpretation of this mathematical relationship?

Short essay

- Choose a topic related to accelerator physics (examples: luminosity; design of interaction-region focusing; measurement of beam emittance; the beam-beam force; applications of synchrotron light; hadron therapy; etc.).
- E-mail your topic to the lecturers for feedback and approval.
- Gather information about the topic from reliable sources, such as textbooks, experts in the field, journals.
- Within these two pages, summarize what you believe are the main aspects of the topic, including relevance, concepts, results, and challenges.