Prof. Dr. Albin F. Wrulich EPFL, Winter Term 2005/2006

Introduction to Particle Accelerator Physics

Tutorial 1 - Problems

Discussion: 8.11.2005 Hand in: 15.11.2005 Solutions: 22.11.2005

---

1. Relativistic Particles
The Swiss Light Source SLS at PSI is operating an electron storage ring. The circumference of this ring is $C = 288$ m. The stored beam has an energy of 2.4 GeV.
a) What is the ideal particle's γ ?
b) What is the ideal particle's β ? Are the electrons relativistic?
c) What is the revolution frequency of the particles in the ring?
d) The *Particle Data Booklet* (can be obtained from `http://pdg.lbl.gov`) claims the mass of the electron is $m_e = 511$ keV/c^2, but also $m_e = 9.11 \cdot 10^{-31}$ kg. Are both statements correct? Show how one can be derived from the other.
e) In 1a) you calculated γ for an ideal electron in the SLS storage ring. In the LHC at CERN protons will be accelerated and brought to collision at 4 interaction points (IP) where the experiments ALICE, ATLAS, CMS, and LHCb are located. The design energy of LHC is 7 TeV which is almost 3000 times higher than the SLS'. What is the γ of an ideal proton in LHC?

2. Dipole Magnets vs. Static Electric Fields
In accelerators, dipole magnets are used to deflect charged particles. The same could be achieved with static electric fields. Why are dipole magnets chosen instead? Assume highly relativistic electrons in a storage ring. What field strengths are necessary in order to apply a certain force on the particles?

3. Cyclotron
PSI operates a high-intensity proton cyclotron. The injection energy is 72 MeV and extraction happens at 590 MeV. How large is the orbit radius at extraction in units of the initial orbit radius? If the cyclotron were to be operated as an iso-cyclotron, what consequence would this have for the magnetic field?

4. Electron Beam in a Storage Ring
Recall the 2.4 GeV electron storage ring at the SLS with a circumference of $C = 288$ m.
a) What dipole strength is required to keep the electron beam on a circular orbit if we assume the storage ring consists of dipole magnets only?
b) Now consider a real storage ring that contains bending magnets but also many straight sections. These are required for components like focussing magnets (quadrupoles, sextupoles, etc.), corrector magnets (kickers, pingers), detectors, insertion devices (wigglers, undulators), RF, etc. The radius of the bending magnets is assumed to be $\rho = 6$ m. What bending magnetic field strength is required to keep the particles on a circular orbit?
c) What about the earth's magnetic field? Assume a peak strength of roughly 30 μT.

Under which conditions will the particles be deflected?
d) We have not considered gravity yet! Compare the forces acting on an electron in the beam. Which is larger, the gravitational force or the bending magnet force?

Assistant: Simon C. Leemann, simon.leemann@psi.ch, 056/310 3343