

- Starting with the Lorentz Force Law in SI units, derive the formula for cyclotronic motion:

$$p \text{ ( GeV/c )} = 0.3qBR \quad (1)$$

- The LHC will be a 27 km circumference circular synchrotron with a 7 TeV proton beam (and 7 TeV anti-proton beam). It is the same size as LEP which had a 100 GeV electron beam (and a 100 GeV positron beam).
  - What magnetic field strength was required at LEP to keep the electrons rotating in the ring?
  - What magnetic field strength will be required at the LHC to keep the protons rotating in the ring?
  - At what speed is the proton travelling in the LHC?
  - Calculate the energy loss due to synchrotron radiation per turn per proton in the LHC beam in MeV (assume the proton is travelling at the speed of light).
  - If the LHC has 2808 bunches and each bunch contains  $10^{11}$  protons, how much energy is lost per second from synchrotron radiation?
- The International Linear Collider (ILC) is a future linear collider designed to collide 500 GeV electrons on 500 GeV positrons. If the typical field strength of an accelerating cavity is 10 MV/m, how long must the ILC be?
- Consider a highly relativistic proton beam with momentum  $p = 500 \text{ GeV}/c$  incident on a hydrogen target.
  - Calculate  $\sqrt{s}$  for the  $pp$  interaction (assume  $m_p \approx 1 \text{ GeV}/c^2$ ).
  - What beam energy would be required for a  $pp$  collider to achieve the same  $\sqrt{s}$ ? What does this say about the relative benefits of a fixed target and collider experiment?
- The LHC has a 27 km circumference operating as a  $pp$  collider at  $\sqrt{s} = 14 \text{ TeV}$  with 2808 bunches and  $10^{11}$  protons per bunch. The average luminosity will be  $10^{34} \text{ cm}^{-2} \text{ s}^{-1}$ .
  - The strength of the beam is often expressed as a current, as if the beam-pipe was simply a wire with moving charges. What is the total beam current in the LHC in Amps? (remember each bunch can contribute multiple times per second).
  - What is the total energy stored in the LHC beam, in Joules?
  - What is the effective beam cross-section, in  $\text{cm}^2$ ?
  - Assuming that the LHC runs at the average luminosity for 23 hours each day, what will be the integrated luminosity after a month of running (in  $\text{fb}^{-1} = 10^{-39} \text{ cm}^{-2}$ ).
  - If the cross-section for producing a Higgs with mass  $120 \text{ GeV}/c^2$  is 2 pb and the detection efficiency is 1%, how many Higgs bosons will be seen at the LHC in one month?