PHYS6011 Experimental Particle Physics - Problem Set 1 Questions - 2012

1. Starting with the Lorentz Force Law in SI units, derive the formula for cyclotron motion:

$$p\,(\,\mathrm{GeV}/c) = 0.3qBR \tag{1}$$

2. The LHC is a 27 km circumference circular synchrotron with a 4 TeV proton beam travelling in one direction (and another 4 TeV proton beam travelling in the opposite direction) [1]. It is the same size as LEP which had a 104 GeV electron beam (and a 104 GeV positron beam).

   (a) What magnetic field strength was required at LEP to keep the electrons rotating in the ring?

   (b) What magnetic field strength is required at the LHC to keep the protons rotating in the ring?

   (c) At what speed is the proton travelling in the LHC (as a fraction of theh speed of light)?

   (d) 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).

   (e) If the LHC has 1380 bunches and each bunch contains 2.0×10^{11} protons, how much energy is lost per second from synchrotron radiation?

3. The International Linear Collider (ILC) is a future linear collider designed to collide 500 GeV electrons on 500 GeV positrons.

   (a) If the typical field strength of an accelerating cavity is 10 MV/ m, how long must the ILC be?

4. Consider a highly relativistic proton beam with momentum $p = 500\,\mathrm{GeV}/c$ incident on a hydrogen target.

   (a) Calculate $\sqrt{s}$ for the pp interaction (assume $m_p \approx 1\,\mathrm{GeV}/c^2$).

   (b) 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?

5. The LHC has a 27 km circumference operating as a pp collider at $\sqrt{s} = 8\,\mathrm{TeV}$ with 1380 bunches and 2.0×10^{11} protons per bunch. The average luminosity $\mathcal{L}$ is currently $2 \times 10^{33}\,\mathrm{cm}^{-2}s^{-1}$.

   (a) 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).

   (b) What is the total energy stored in the LHC beams, in Joules?

   (c) What is the effective beam cross-section, in cm^2?

   (d) 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 $\mathrm{fb}^{-1} = 10^{-39}\,\mathrm{cm}^{-2}$).

   (e) If the cross-section for producing a Higgs with mass $125\,\mathrm{GeV}/c^2$ is 2 pb and the detection efficiency is 2%, how many Higgs bosons will be seen at the LHC in one month?

[1] The LHC beam energy was increased from 3.5 to 4.0 TeV in April 2012