

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

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

- The LHC is a 27 km circumference circular synchrotron with a 7 TeV proton beam travelling in one direction (and another 7 TeV proton beam travelling in the opposite direction). It is the same size as LEP which had a 104 GeV electron beam (and a 104 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?
 - If the cost of electricity is about 1€ per watt per year, what is the annual electricity bill to replace the energy lost by synchrotron radiation in the LHC?
- 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 \mathcal{L} 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 beams, in Joules?
 - What is the effective beam cross-section, in 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 2%, how many Higgs bosons will be seen at the LHC in one month?