PHYS6011 Experimental Problem Set

Part I

1. Starting with the Lorentz Force Law in SI units, derive the formula for cyclotronic motion in the units used in the lecture notes:

$$p = 0.3qBR$$

2. The LHC will be a 27 km circumference circular synchrotron with a 7 TeV proton beam. It sits in the same tunnel and is exactly the same size as LEP which had a 100 GeV electron beam.

   (a) What is the field strength of the LHC dipoles?

   (b) What was the field strength of the LEP dipoles?

   (c) Calcuate the energy loss per turn of a particle in the LEP beam in MeV.

   (d) Estimate the total length of accelerating cavities required at LEP

3. Consider a highly relativistic proton beam, $p = 500$ GeV, incident on a hydrogen target.

   (a) Calculate $\sqrt{s}$ for the $p + p$ interaction.

   (b) What beam energy would be required at a $p - p$ collider to achieve the same $\sqrt{s}$?

4. The Fermilab Tevatron is a synchrotron with a radius of 1.0 km operating as a $p\bar{p}$ collider at $\sqrt{s} = 1.96$ TeV. As I write, there are $7.9 \times 10^{12} p$ and $1.1 \times 10^{12} \bar{p}$ loaded (each in 36 bunches) and the DØ experiment is measuring a luminosity of 54×10^{30} cm^{-2}s^{-1}.

   (a) The strength of the beam is often expressed as a current, as if the beampipe were simply a wire with moving charges. What is the total beam current in the Tevatron, in amps? (Remember each bunch can contribute multiple times)

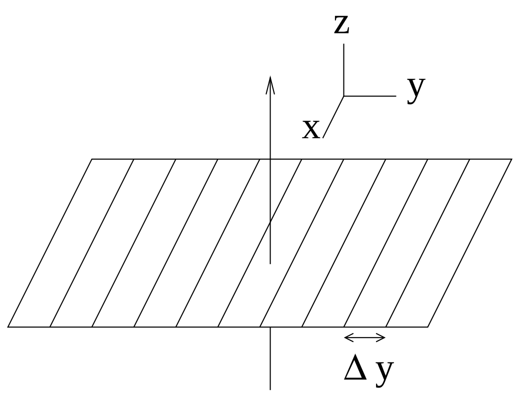

Figure 1:

(b) What is the total energy stored in the Tevatron beam, in Joules?

(c) What is the effective beam cross sectional area at DØ?

(d) Assuming that the current luminosity is a reasonable average figure over a 22 hour store, and that the Tevatron spends 2 hours filling between stores, what integrated luminosity will DØ see in a week of running (in pb^{-1})?

5. A 10 GeV muon can be treated as a MIP with mean $dE/dx \approx 1.5$ MeV g^{-1}cm^2 in most materials.

   (a) What is the rate of energy loss of a 10 GeV muon travelling through pure nitrogen at atmospheric pressure (in MeV/m)?

   (b) Estimate the range (i.e. the distance travelled before coming to rest) of a 10 GeV muon travelling through steel.

6. Consider a wire or strip detector in the xy plane, with thin detector elements in the x direction separated by a distance (pitch) Δy as shown in Figure 1. A particle travelling in the z direction will register as a hit on a single detector element. Show that the intrinsic resolution (defined as the r.m.s. distance between the measured and true particle positions) is given by $\Delta y/\sqrt{12}$.

7. A 4 m long TPC was used very successfully as the main tracking detector for the ALEPH experiment at LEP. Explain why a similar device was not considered for the CMS or ATLAS experiment at the LHC.

8. Consider a strip detector made from 300μm thick 5 kΩ cm silicon.

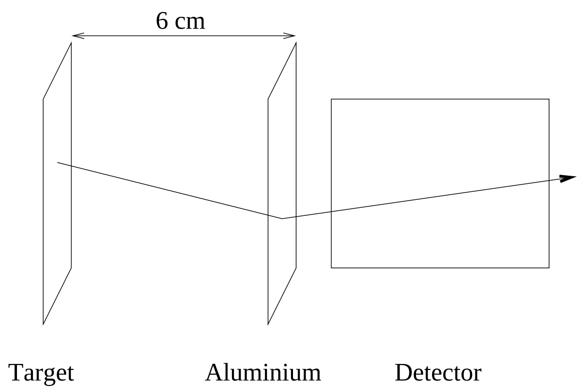

Figure 2:

(a) What applied voltage is required to fully deplete the silicon?

(b) What is the mean energy deposited by a MIP traversing normally to the wafer?

(c) Calculate the energy required on average to create an electron-hole pair. Why is this greater the 1.1 eV band gap in silicon?

9. An electromagnetic calorimeter is made from layers of 1 mm thick tungsten interspersed with 1 mm layers of scintillator. Tugsten has $Z = 74, A = 184$ and a density of 19.3 g/cm^3.

(a) What is the radiation length of tungsten?

(b) A very simplified description of an EM shower is that every X_0 the number of particles increases by a factor of two with the energy of each particle being halved. The shower will stop when the particle energy falls below the critical energy. Estimate the total thickness of the calorimeter required to completely contain the shower caused by an incident 100 GeV electron. (The critical energy in tungsten is 8.3 MeV, and you may ignore interactions in the scintillator).

(c) If the density of the scintillator is 1.1 g/cm^3, what is the total ionisation energy deposited in the scintillator by the particles in the shower? (treat all particles as MIPs)

(d) If the efficiency of detecting a scintillation photon is 5%, how many photons will be collected in total?

(e) How many nuclear interaction lengths thick is this calorimeter?

10. (a) Write down the expression for the RMS scattering angle for a particle passing through a 1 mm layer of aluminium as a function of the particle momentum.

(b) A tracking detector precisely measures the trajectory of a 500 MeV pion in order to measure its exact point of production within a plane target 6 cm in front of the detector. What is the error in the measurement caused by the presence of a 1 mm Al layer 6 cm from the target (see Figure 2)