Exercises

1. (5 p)

   Protons and α particles of 20 MeV pass through a 10-μm-thick aluminium foil. How much energy do these two types of particles deposit in the foil?.

2. (5 p)

   Multiple-scattering often limits the ability to measure the direction of motion of charged particles. To what accuracy can the initial direction of a 100 GeV muon be estimated if the direction is measured after traversing 30 cm of steel?.

3. (5 p)

   Assume the particles e, μ, π, K and p, each with 1.5 GeV momentum traversing a medium with index of refraction n = 1.5. Which particles will emit Cherenkov radiation?

4. (15 p)

   An extensive cosmic ray shower strikes the earth, which we assume to be uniform quartz (SiO2) rock of density $3g/cm^3$. The shower has a core of 1000 GeV muons, and a broad distribution of electrons of energies between 10 GeV and 100 GeV.

   - Assuming that the muons ionize minimally until they stop, how deeply do the muons penetrate?
   - At this depth, what fraction of its original energy remains in the electron component of the shower?

5. (20 p)

   An experiment searching for proton decay in the mode $p \to e^+ + \pi^0$ is carried out using a cubical tank of water as the proton source. Possible decays are to be detected using the Cherenkov light emitted when the electromagnetic showers from the decay products traverse the water.

   - How big should the tank be in order to contain such showers if they start in the centre?
   - Estimate the total track length integral (TLI) of the showers from a decay event

- Assuming a typical light yield of 5%, estimate the total number of photons emitted in the visible region (1 eV).
- If the light is detected by means of an array of photomultipliers at the water surface, the effective optical transmission of the water is 50% and the photocathode efficiency is 20%, what fraction of the surface must be covered by photocathode to give an energy resolution of 5%?

  (The radiation length and critical energy of water are approximately 433 mm and 70 MeV respectively)

6. (5 p)

   Assume a non-stable charged particle with mean lifetime of τ circulating in a synchrotron whose dipoles have a magnetic field B and occupy half its circumference (dipole fill factor of 0.5)

   - Obtain an expression for the number of turns that this particle will travel around the synchrotron during the particles mean lifetime at the lab reference system as a function of the dipole magnetic field B
   - Apply this obtained expression for the muon

7. (15 p)

   An electron transport line is made of the following elements (the beam line starts at $z = 0$): $drift(0.5m)+QF+drift(1m)+QD+drift(0.5m)$

   - At $z = 0m$, the beam horizontal $\beta - function$ is $\beta_x = 10\ m$ and the vertical $\beta - function$ is $\beta_y = 12\ m$. The beam geometric R.M.S. emittance is 1 $mm\ mrad$. Estimate the horizontal R.M.S. beam size at $z = 0$.
   - The quadrupoles have a focal length of 2 m. QF-type quadrupoles are focusing in the vertical plane and QD-type quadrupoles are focusing in the horizontal plane. The quadrupoles can be considered to have a negligible length (zero-length thin lens approximation). Consider a particle located at $y = 1mm$ above the beam axis at $z = 0m$ and with no transverse momentum. Use matrix multiplications to estimate the particles position with respect to the beam axis at $z = 2.5m$.

8. (15 p)

The focusing used in accelerators based on the use of couples of quadrupoles is call strong focusing. Other type of focusing, named week focusing, is based on the use of a filed like $|\vec{B}(R)| = B_0 \left(\frac{R}{R_0}\right)^{-n}$, $0 < n < 1$ (shown in figure 1) along the complete path of the particle. Prove that both equations of motion, on the vertical and the horizontal plane, are harmonic oscillators and find the frequency.

NOTE: use the lineal approximation for the magnetic field around the stable orbit (of radius R_0)in both cases.

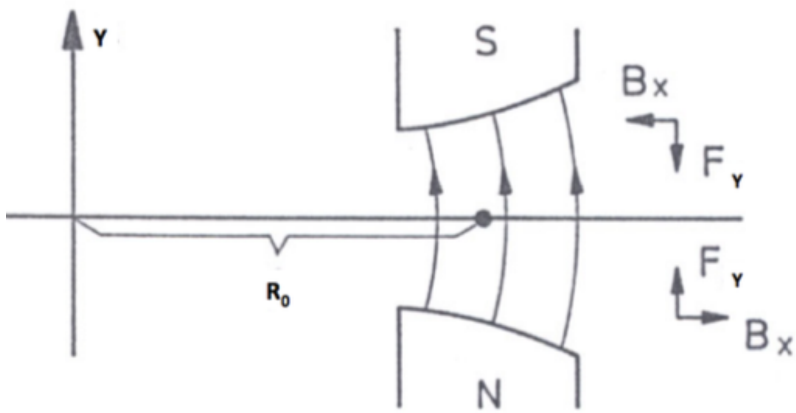

Figure 1: Magnetic field in weak focusing

9. (15 p)

The betatron is a circular induction accelerator (shown in figure 2). A varying magnetic field B_a is used to accelerate the particles by induction while the magnetic field B_g is used to maintain the particle in orbit.

Find the mandatory relation between B_g and B_a to maintain the radius of the orbit when B_a is varying to accelerate the particle by induction.

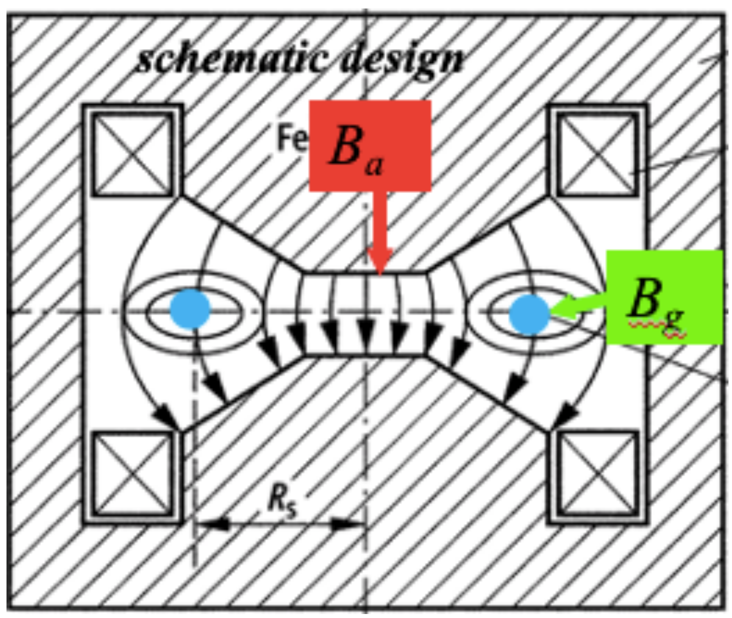

Figure 2: The Betatron. The orbit of the particle is perpendicular to the figure plane, leaving and entering it at the points shown by the blue dots.