Physics 400/506
Problem Set 2
Due Tuesday January 31, 2006 by the end of class

1. Synchrotron radiation limits the energy of a circular e^+e^- accelerator. As a way around this problem, there is serious interest in building a *muon collider* ($\mu^+\mu^-$).

A What is the ratio of the synchrotron loss at a circular muon collider to that of an electron collider with the same energy and diameter?

B What is the ratio of the synchrotron loss at a circular muon collider to that of a *proton* collider with the same energy and diameter?

C Given your answer to the previous question, explain why it still might be advantageous to build a muon collider.

D If the final beam energy is 1 TeV, and the mean magnetic field in the ring is 2 Tesla is then, what is the radius of the of the storage ring needed to contain the beam?

E The muons will of course decay, and must be accelerated quickly. Suppose that muons are injected into this ring with an initial energy of 10 GeV, but must be accelerated to a final energy of 1 TeV. If the muon gains an energy of 2 MeV during each pass through the storage ring, what fraction of the muons will decay before reaching their final energy of 1 TeV? *Note: a muon always decays by* $\mu^- \rightarrow e^-\nu_\mu\bar{\nu}_e$. *If you built a muon collider with straight sides (like a racetrack), then muons decaying in the straight segments would produce a collimated, energetic neutrino beam. This idea is commonly called a "neutrino factory".*

2. A minimum ionizing muon passes perpendicularly through a 1 cm thick sodium iodide scintillator paddle.

A How many grams/cm^2 of material does the particle encounter? (You may need to look up some data on NaI material properties in the back of the Particle Data Booklet).

B How much energy does the particle lose to ionization?

C Assume that 10% of the deposited energy is in the form of visible light. If the mean photon energy is 3 eV, how many photons are produced?

3. IceCube is a project to instrument the Antarctic ice with photomultiplier tubes in order to detect high energy neutrinos from the cosmos. Typically the neutrinos will interact via $\nu_\mu + n \rightarrow \mu^- + p$. The muon is then tracked by detecting the Cherenkov radiation that it produces.

A What is the energy threshold for a muon to produce Cherenkov light in the ice?

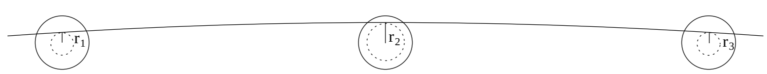
B What is the minimum neutrino energy needed to produce a muon above the Cherenkov threshold?

C What is the Cherenkov cone angle of the muon in the relativistic limit?

4. A completely ionized beam of ^{4}He with a kinetic energy of 10 MeV/nucleon enters a 2 m long dipole magnet. You wish to deflect the beam by 10°. Compute the strength of the needed magnetic field.

5. A radioactive source emits gamma rays of 1.1 MeV energy. The intensity of these gamma rays must be attenuated by a factor of 10^4 by a lead sheet. How thick (in cm) must the sheet be?

6. *Graduate students only:* A charged kaon passes through three tubes of a tracking hodoscope. The three tubes are all in a line, with a spacing of 25 cm, as shown below.



Timing measurements are used to determine the impact parameter of the particle in each tube, as follows:

$$
\begin{aligned}
r_1 &= 40 \pm 20 \mu m \\
r_2 &= 170 \pm 20 \mu m \\
r_3 &= 40 \pm 20 \mu m
\end{aligned}
$$

Assume that the track passed through the top half of each tube, as shown in the diagram. If the magnetic field is 0.5 Tesla along the axis of tube (into the page), what is the momentum of the kaon, and what is the uncertainty on its momentum?