Name: Group:

Problem sheet 4 - Physics V - WS 2007/2008

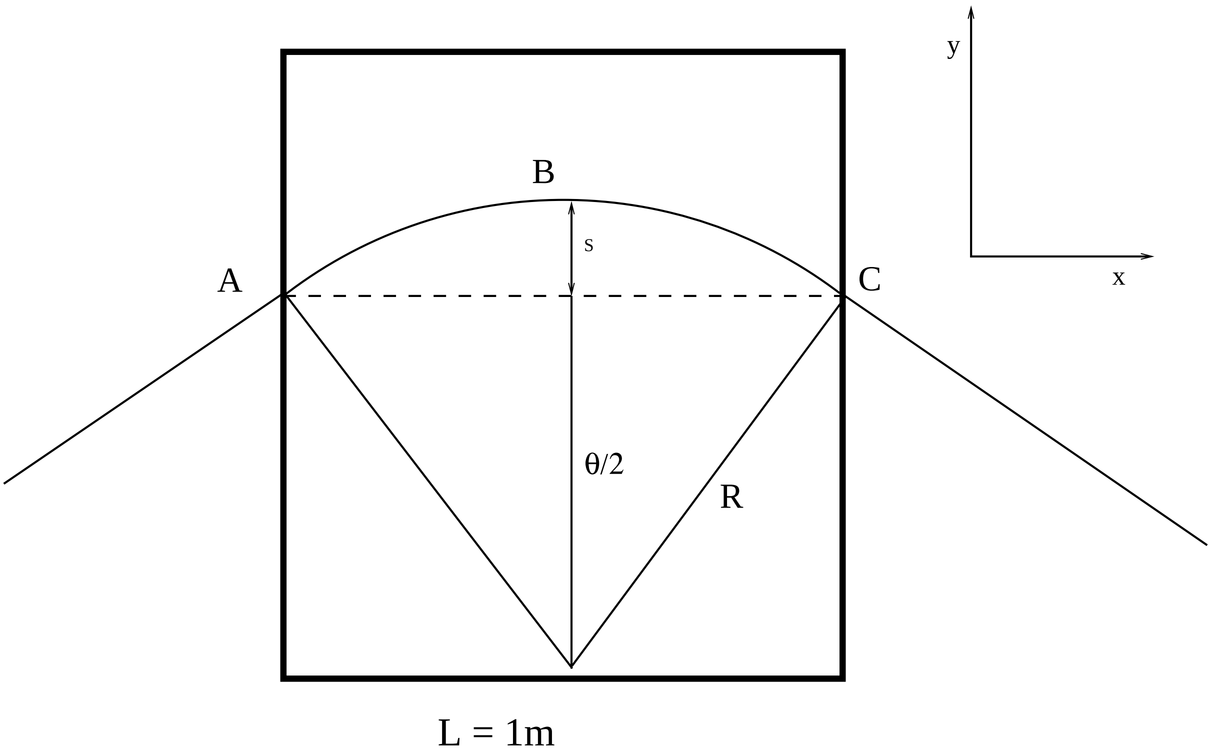
Due: November 15/16, 2007

Problem 4.1: Momentum measurement (25 Points)

The momentum of a charged particle can be determined in a homogeneous magnetic field B of length L, see figure below.

a) Derive an expression for the radius of the curvature R as a function of the particle's momentum, p_t, transverse to the magnetic field. Express the sagitta s of the curved track segment as a function of R, assuming that the angle of deflection θ is small ($L/R \ll 1$).

b) The trajectory of the particle will be measured at three equidistant points, A, B and C with equal resolution in the y-direction σ_y, from which the sagitta can be determined. Assume that the three measurements are uncorrelated. Determine the relative momentum resolution $\sigma(p_t)/p_t$ obtained from this measurement. *Hint: Note that one endpoint of the sagitta is determined by the measurement at point B, the other one by the two measurements at points A & C.* The magnetic dipole is $L = 1$ m long, with a field strength $B = 1$ T and resolution along y: $\sigma_y = 200\ \mu$m. The particle's momentum $p_t = 1$ GeV.



Problem 4.2: Particle identification using time of flight (25 Points)

As you know, the distance a particle traverses in a medium depends on the velocity and mean free path for the type of particle. Therefore, when the momentum of a particle is known, *e.g.* from the curvature of the particle through the magnetic field, its mass can be determined from

$$\vec{p} = m\gamma\vec{\beta}$$

and the knowledge about its velocity. The velocity can be measured by determining the Time Of Flight (TOF) of the particle between two scintillation counters. Imagine that one would like to separate pions from kaons up to a momentum of $p = 25$ GeV. The light generated by charged particles traversing the scintillation counters is collected in photo multiplier tubes. Assume that these have a resolution of $\sigma_t = 0.5$ ns.

a) How far apart should the scintillation counters be, in order to be able to separate pions from kaons with at least three standard deviations? Use the relation

$$\sigma_t < \left| \frac{1}{3} \Delta t_{\pi,K} \right|,$$

with $\Delta t_{\pi,K}$ the difference of the time-of-flight of a pion and a kaon. Given the size of *e.g.* the Atlas detector (about 20 meters high), or the LHCb detector (about 15 meters long) argue the practibility of using such scintillation counters for particle identification.

b) Plot Δt as a function of the particle momentum in a momentume range from 1 GeV till 40 GeV for pions and kaons, kaons and protons.

Problem 4.3: Calorimetry (25 points)

The energy of charged, and also neutral particles can be meausured by two different types of calorimeters. There is the so-called Electromagnetic Calorimeter (ECal), in which particles cause an electromagnetic shower. In the 2nd type of calorimeter, a particle looses energy through a hadronic shower. This then is a Hadronic Calorimeter, or HCal.

a) In which way do these two showers differ from each other?

Ideally, the magnitude of the measured signal in an ECal depends linearly on the number of produced photons in the shower, and hence linearly on the deposited energy of a traversing electron. The uncertainty on the measurement is of statistical nature since it depends on the number of detected photons.

b) How does the energy resolution $\Delta E/E$ dependent on the energy of the absorbed electrons?

c) Explain the different energy resolution of a hadronic calorimeter compared to an electromagnetic calorimeter.

d) Consider an electron with a momentum of 10 GeV incident on an ECal with a typical momentum resolution of $\Delta p/p = 0.02$. Calculate the momentum for which electrons will have the same energy resolution when $\Delta E/E = 0.04$.

Problem 4.4: Ring Imaging Cherenkov Counter (25 Points)

Given the result of Problem 4.2, an alternative would be to use a (threshold) Cherenkov counter. Here, particles which traverse a medium at a speed larger than the speed of light in that medium, emit Cherenkov light:

$$\cos\theta_c = \frac{1}{n\beta},$$

with n the refraction index of the medium and β the relativistic velocity.

One can use the Cherenkov light detection in a so-called Ring Imaging Cherenkov Counter, or RICH. Such detectors are used to identify pions, kaons and protons. For a new experiment, such a RICH is under consideration.

a) explain the difference between a RICH and a (threshold) Cherenkov counter.

In one of the RICH's, Aerogel radiators are used, because of their limited thickness (why is that important?). As an alternative, one could use for instance CF_4 as a radiator. The indices of refraction are $n_{CF_4} = 1.0005$ and $n_{\text{Aerogel}} = 1.03$.

b) The angular resolution on the Cherenkov angle is $\sigma(\theta_{\mathrm{CF_4}}) = 0.6$ mrad and $\sigma(\theta_{\mathrm{Ae}}) = 2.0$ mrad for Aerogel. Calculate the Cherenkov angles for both radiators for pions and kaons at $p = 12$ GeV/c and $p = 55$ GeV/c. Are you still able to distinguish a pion from a kaon? (Assume a minimum separation of 1 σ.)

c) The momentum range of pions and kaons at this experiment is rather large: $0.5 < p < 100$ GeV. Which would be the better radiator, or should one maybe use both? Explain why.