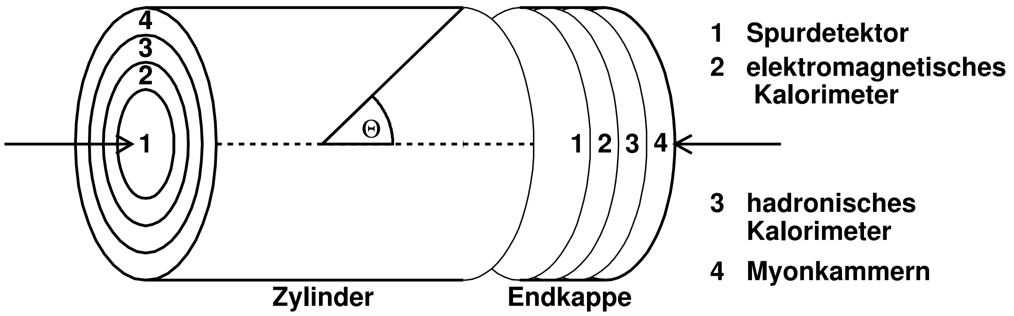
E5 Kern- und Teilchenphysik
WiSe 17/18 – Exercise 5

Discussion: 19.12.2017 bis 08.01.2018

Students studying "Lehramt Gymnasium" please solve the exercises 1a, 2 und 3. All other students please solve all exercises.

1. We're Crafting a Collider Detector



1 Tracking detector, 2 electromagnetic calorimeter, 3 hadronic calorimeter, 4 muon chambers

(a) What is the radius for a detector with the following parameters?

- Beam pipe diameter 4 cm.
- Magnetic field $B = 4\,\mathrm{T}$.
- A statistically attainable resolution of 1.5 % for a transverse momentum $p_T = 100\,\mathrm{GeV}/c$ (Assumption: silicon strip detector with 20 measurement planes, each with an intrinsic spatial resolution of $\sigma = 30\,\mu\mathrm{m}$.)
  Hint: Empirical formula for the statistically attainable momentum resolution$\sigma(p_t)$ for N evenly spaced measurements with a spatial resolution of $\sigma(x)$ over a length L perpendicular to a homogeneous magnetic field B is

$$\frac{\sigma(p_t)}{p_t} = \frac{\sigma(x)}{a\,B\,L^2}\sqrt{\frac{720}{N+4}} \cdot p_t,$$

  with $a = 0.3\,\mathrm{T}^{-1}\,\mathrm{m}^{-1}\,\mathrm{GeV}/c$.
- homogeneous electromagnetic calorimeter with $26\,X_0$
  (Assumption: lead tungstate ($PbWO_4$) crystals with a radiation length $X_0 = 0.89\,\mathrm{cm}$).
- hadronic sampling calorimeter with $\geq 7\,\lambda_a$ consisting of alternating layers of 5 cm brass ($\lambda_a = 18.4\,\mathrm{cm}$) and 4 mm scintillator plates. Assume that only the brass layers are relevant for the shower development.
- Reconstruction of muon track segments in the magnetic reflux joke (instrumented iron) with a thickness of 3 m.

(b) **Optional for Lehramtsstudierende:** How long does the cylinder have to be so that particles from the interaction point which fly at an angle to the beam axis of $\cos\theta \leq 0.7$ pass the full radius of the tracking detector?

(c) **Optional for Lehramtsstudierende:** How long is the detector if you build the two end caps (Endkappen) consisting of tracking chamber, calorimeter and muon chamber exactly as in exercise (a)?

2. Particle Identification

A particle takes a flight time of 6.9 ns for a flight distance of 2 m. It has a specific energy loss of

$$-\frac{1}{\rho}\left\langle\frac{\mathrm{d}E}{\mathrm{d}x}\right\rangle = 8\,\frac{\mathrm{MeV\,cm^2}}{\mathrm{g}}.$$

Its trajectory has a curvature radius of $R = 25$ m in a homogeneous magnetic field of 1 T. Calculate the charge, momentum and mass of the particle and identify it! *Hint:* First calculate $\beta\gamma$ without resorting to the $\mathrm{d}E/\mathrm{d}x$ formula.

3. Storage Rings at CERN

The electron positron storage ring LEP was operated in the accelerator tunnel at CERN (27 km circumference) up to the year 2000 with a final center of mass energy of 209 GeV. The same tunnel now contains the proton proton storage ring LHC which has been designed for center of mass energies up to 14 TeV.

(a) What is the required magnetic field for the beamline deflection (dipole magnets) of LEP? Assume that the whole circumference is filled with dipole magnets.

(b) What energy must be transferred to each electron per revolution (by cavity resonators) in order to reach a center of mass energy of 209 GeV? What is the total electrical power of the cavity resonators when the beam currents are 5 mA (assumption: efficiency 1)?

(c) Calculate the energy loss per revolution by synchrotron radiation if LHC were operated as an electron-positron storage ring. What is the energy loss for protons?

(d) What is the minimum required magnetic field strength for the deflection magnets of LHC? (with the assumption from task a) Why is their maximum field strength in reality 8.3 T?