Experimental Particle Physics

ESIPAP 2014

Teacher: Marco Delmastro (LAPP, Annecy-le-Vieux)

Exam

January 31, 2014

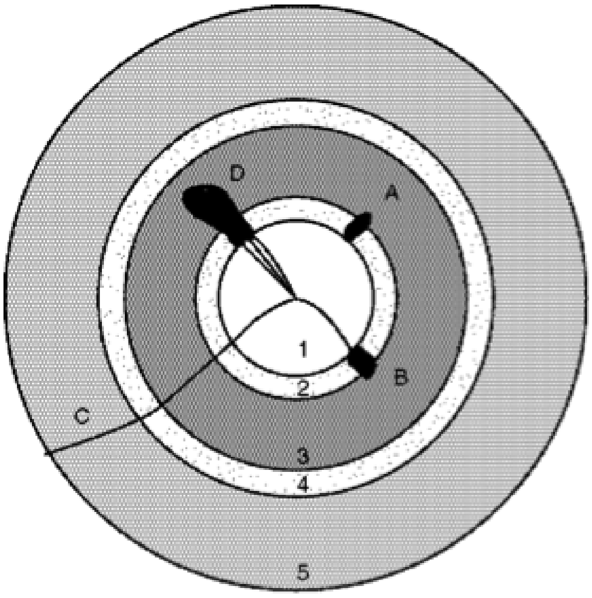
The exam is divided in three parts:

1. *A series of a short questions, which you should provide* **short** *answers to.*
2. *Three simple problems, similar to those we solved during the tutorials. Each problem is split into different questions of increasing difficulty, with a final "bonus" question for the fastest calculators among you.*
3. *A short paper to read and understand, again with some questions to answer to.*

For a full mark, you should correctly reply to the short questions, solve about two problems out of three (not counting the "bonus" questions), and properly address the questions regarding the paper. **Before you dive into the exam, take a few minutes to review its content, and carefully plan how to use your time (you have 1.5 h).** *You can use any material (e.g. the lectures slides, books, the PDG booklet). Use your wisdom to choose proper rounding and approximations in your calculations (and remember: wisdom will be evaluated!).*

Your name here

1 Questions on high-energy physics experiments at colliders



The above figure represents an approximate section of a general purpose detector for a colliding-beam high energy physics experiment. Four particles, or groups of particles, are coming from the interaction point. The labels 1, 2, 3, 4 and 5 refer to an inner tracking detector, an electromagnetic calorimeter, a hadronic calorimeter, a solenoid magnet and a muon tracking system.

1. *Briefly* explain the purpose of each of these systems.
2. Why is the calorimetry system divided into two parts? What are the different attributes of each part?
3. Identify the four objects labeled A, B, C and D. Explain your identification.

2 Problems

2.1 Energy and momentum measurements

In a fictitious high-energy physics experiment, the inner tracking detector (ID) has a momentum resolution:

$$\frac{\delta p}{p} = b \cdot p$$

with $b = 5 \cdot 10^{-4}\,\mathrm{GeV}^{-1}$, while the electromagnetic calorimeter (ECAL) has an energy resolution

$$\frac{\sigma_E}{E} = \frac{a}{\sqrt{E}}$$

with $a = 5\%\sqrt{\mathrm{GeV}}$.

1. What are the momentum and energy resolution in the two subdetectors for an electron with E_e = 1 GeV, 10 GeV and 100 GeV respectively? You can safely assume $E_e \simeq p_e$: estimate what is the bias of this assumption for the 1 GeV case.

2. What is the momentum range where the measurement with the ID is more precise then the energy measurement in the ECAL?

3. Some colleagues of yours are suggesting to upgrade the current ID setup, and increase solenoid magnetic field from 2 T to 3 T. How would the momentum resolution improve should you upgrade the solenoid?

4. **[BONUS]** Would it be convenient to combine the measurements of ID and ECAL? Why? Assuming that the uncertainties on the ID and ECAL measurements are uncorrelated, define the combined momentum measurement as the weighted mean of p and E, and compute what would be the uncertainty of such measurement for an electron with E = 20 GeV.

2.2 Particle identification

A beam of 20 GeV momentum consists of a mixture of positively charged pions and kaons. You want to be able to distinguish the two types of particle on the basis of their difference in speed.

1. Compute the difference in speed $\Delta\beta$ in units of c.

2. You want to use a threshold Cherenkov detector to distinguish the particles. Threshold Cherenkov detectors usually adopt a gas as a radiator: the gas pressure can be modified to adjust its refractive index to the need of the experiment, so that only particle with specific properties would emit light in the detector. You want to set the counter so that the 20 GeV kaons are at threshold, and they will not emit light. What should the n the refractive index n of the radiator be?

3. Given you choice of n, the pions would then be well above the threshold, and any particle which gives detectable Cherenkov photons is identified as a pion. What would be the angle θ_C which the Cherenkov light from pions would be emitted at?

4. Suppose that the beam is not perfectly monochromatic, but is instead uniformly distributed between 19 GeV and 21 GeV for both pions and kaons. What is the fraction of fraction of kaons wrongly identified as pions? Would there be a fraction of pions that would mistakenly identified as kaons?

5. **[BONUS]** If your detector is not perfectly efficient, you will not always collect all the Cherenkov light emitted by pions. Additionally, the number of emitted photons by a traversing pion would not be always the same. Assuming the lenght of your radiator is such that each pion emits on average 5 photons while traversing it and that your detector is only 80% efficient, what would be the fraction of pions in a monochromatic beam wrongly identified as kaons? Hint: the number of photons from a given pion will be distributed as a Poisson distribution.

2.3 Particle production at colliders

You want to build an experiment to produce large samples of the $\Upsilon(4S)$ meson. This neutral particle, with a mass of 10.58 GeV, can be produced by colliding e^+e^- beams at this center of mass energy.

1. Would would need to be the energy of the e^+ and e^- beams to produce the $\Upsilon(4S)$ meson at rest?

2. If you want to produce the $\Upsilon(4S)$ particle with a velocity parameter $\beta = 0.6$ in the laboratory frame, what should be the e^+ and e^- beam energies?

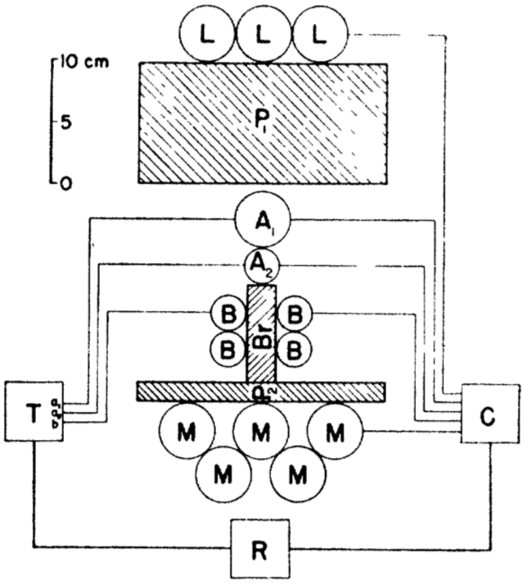
3. The $\Upsilon(4S)$ is known to decay, with a very short lifetime, to pairs of B mesons ($m_B \simeq 5.28$ GeV), for instance
$$\Upsilon(4S) \to B^+B^-$$
These particles can be considered to be produced at rest in the center-of-mass frame. They subsequently decay themselves with a lifetime at rest $\tau = 1.6$ ps. What would the mean distance in the laboratory frame they travel before decaying if the $\Upsilon(4S)$ is produced at rest? What would it be if the $\Upsilon(4S)$ is produced with $\beta = 0.6$? Hint: the decay lenght of a moving particle can be computed in the laboratory frame as:
$$\ell = \gamma\beta c\tau$$
where $\gamma\tau$ would be the lifetime considering time dilatation, and βc accounts for the speed of the particle in the laboratory frame.

4. **[BONUS]** Find the probability for a B meson produced in such an interaction to travel a distance of more than 2 mm before decaying.

3 Analysis of a classic particle physics experiment

B. Rossi and N. Nereson, Experimental determination of the disintegration curve of Mesotrons, Phys. Rev. 62, p. 417, 1942

This is one of the seminal papers of Bruno Rossi et al., where the lifetime of muons from cosmic rays were measured with great precision and with a clever experimental setup (muons were still called *mesotrons* in 1942!). Read the paper with attention, and provide synthetic answers to the following questions, making reference when needed to the experimental setup displayed in Figure 4 of the paper, and shown below.



1. The muon decays are identified by detecting the electrons emitted in their decay. How are these electrons detected? What is measured? What detector provide the signal?
2. What is the role of the L and M counters?
3. List the detectors that must give a signal to indicate a muon decaying in the Br plate. What must be the state of the counter M to declare a muon event?
4. Why the setup uses the lead plate P_1 and P_2? Why P_2 has a smaller thickness then P_1? What would be the consequences of removing P_2 from the setup?
5. What events can give a fake muon signal in the apparatus?
6. How is the muon lifetime measured?
7. How do the experimenters prove that the measured time delays can only be explained by the decay of a particle, and not by spurious sources (e.g. natural time lag between the counters, or spurious coincidences)?
8. What is the dominant source of uncertainty in the measurement?