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PHZ4390
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Homework 7

Due Wednesday, Oct. 23

1. The design of HEP experiments was discussed in the note on charged particle measurements. Use that note plus google searches to answer the following questions.
    a. (3 pts) Why is the tracking detector always the innermost particle subdetector?
    b. (3 pts) Why is the muon detector almost always the last subdetector?
    c. (3 pts) Why do hadron calorimeters have worse relative energy resolution than electromagnetic calorimeters?
    d. (5 pts) What would happen if an electromagnetic or hadron calorimeter was not thick enough? What are the tradeoffs involved in making them thicker?
    e. (5 pts) What strategies can be pursued for improving tracking momentum resolution? What are their tradeoffs?
2. A charged particle with 50 GeV of momentum moves at 30 degrees relative to the z axis through the 3.8T magnetic field at CMS. A total of 17 measurements are made in tracking layers ranging in radius from 3.5 cm to 1.05m.
    a. (10 pts) What is the approximate sagitta in cm of the arc made by the particle between those layers?
    b. (5 pts) If the sagitta is measured with an absolute accuracy of 25μm, what is the relative error on the transverse momentum?
    c. (5 pts bonus) Refer to (b). At approximately what momentum will the ambiguity in the charge of the particle become significant?
3. (10 pts) A time of flight system performs particle ID by measuring the time it takes for a particle of a measured momentum to travel a known distance between two scintillator counters. Estimate up to what particle momentum one can distinguish between charged kaons ($m \sim 500$ MeV) and charged pions ($m \sim 140$ MeV) using two scintillator counters separated by 3.5 m with a flight time resolution of $\sigma = 90$ ps. Assume that to reliably distinguish between two particles of the same momentum, their times of flight must differ by at least 2σ, i.e. $\Delta t \geq 2\sigma$. Hint: This problem is most easily solved by writing the velocity in terms of momentum and expanding to lowest order in m^2 / p^2.
4. (10 pts) A gas Cerenkov device is used in threshold mode to distinguish pions from kaons at $p = 20$ GeV/c. What is the minimum length the device should be able to distinguish the two particle species, assuming that 12 photons are necessary for detection and that only photons in the wavelength range 300 – 600 nm can be detected? These devices are discussed in Chapter 3 of M&S and in my note on charged particle measurements.

5. In a e^+e^- colliding beam experiment we wish to measure the cross section of inclusive $B^\pm$ production through the process $e^+e^- \to B^\pm + X$, where B^- or B^+ decays via the process $B^- \to D^0\pi^-, D^0 \to K^-\pi^+$ (plus charge conjugate or "+ CC") Note that we only measure the "final state" charged particles from the $B^\pm$ decay along with other particles produced in the collision. The 3-momenta of the charged kaons and pions are measured to high precision in the tracking drift chamber, as we discussed in class. The energy is computed for each particle hypothesis by using the appropriate mass in the formula $E = \sqrt{p^2 + m_i^2}$, where m_i is the mass of the assumed type (i = electron, muon, charged pion, charged kaon or proton). A single track can have as many as five 4-momenta, one for each particle type, which differ only in the energy component. Partial identification of which charged particles are electrons, muons, pions, kaons or protons is performed by a RICH (Ring Imaging CHerenkov) detector.

   a. (3 pts) At high energy, the fraction of e^+e^- events producing a $b\bar{b}$ pair is about 11%. Each b quark or antiquark has a 40% chance of producing a charged B meson (the rest are neutral B or B_S mesons or B baryons). Using the branching fractions in the PDG tables, determine approximately how many events will have a charged B meson decaying via $B^- \to D^0\pi^-, D^0 \to K^-\pi^+$ + CC out of 100M total e^+e^- events.

   b. (1 pt) If the average charged multiplicity is 6.2 in events where a $B^\pm$ decays through this decay channel, how many charged particles are on average not associated with the $B^\pm$ decay? These extra charged particles contribute to "combinatoric" background to a decay, i.e., combinations that include one or more wrong particles in the invariant mass. When we carry out data analysis we look for ways to sharply reduce this combinatoric background so that the decays we are looking for are not swamped.

   c. (3 pts) Suppose a particular event has 5 charged particles, 3 positive and 2 negative. Assume that you cannot measure the particle type of any of the particles (i.e., 3-momentum is measured accurately by the tracker but there is no particle ID), how many independent 2-particle invariant mass combinations ($D^0 \to K^-\pi^+$ + CC) are there?

   d. (3 pts) Refer to (c) again. If only one of the combinations in (c) yields an invariant mass close to the D^0 mass, how many $D^0\pi^-$ combinations must be computed to search for the corresponding B decay? Compare this number to the number of combinations that would be required if you didn't select on the D^0 mass first in the $K^\pm\pi^\mp$ invariant mass. (Be careful because when you find a particular combination near the D^0 mass, that determines whether it is a D^0 or $\bar{D}^0$.)