Problem set for the lecture

Particle Detectors, WS 2015/16

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Problem set 11

Deadline: Thursday January 28, 10am

(Please drop into mailbox number 1 on the ground floor of the Gustav-Mie building.)

1. **Transition Radiation**

   With a relativistic electron passing a thin foil, the per-foil yield of photons with frequencies higher than a lower limit ω can be approximated as [1]:

   $$N = \frac{\alpha}{\pi}(\ln\frac{\omega_c}{\omega}(\ln\frac{\omega_c}{\omega} - 2) + \frac{\pi}{12} + 1)$$

   where α is the fine structure constant, and ω_c an upper cutoff frequency.

   (a) Calculate the yield/foil for ω_c =100 keV and ω=500 eV.

   (b) What is the minimum number of foils required to have a probability of at least 90% to get at least one transition radiation (TR) photon per incident electron?

   (c) Three detectors are used in series, for each one an incident electron has a probability of 90% to cause a "high-treshold hit" (indicating a TR photon), while a proton has a probability of 5% to erroneously cause such a hit. A specific particle is observed to cause two high-threshold hits. What is the likelihood L_e that the particle was an electron, using $L_e = \frac{W_e}{W_e+W_p}$, where $W_{e(p)}$ is the probability of the two out of three hits resulting from an electron(proton).

   (2 Points)

2. **Threshold Cherenkov Counters and Time of Flight**

   A detector built for particle identification of charged hadrons consists of three threshold Cherenkov counters. The radiators of the counters consist of A) Aerogel with a refractive index $n_A = 1.022$, B) Aerogel with n_B=1.005 and C) Neopentane with $n_C = 1.00177$. The momentum of incident particles was determined by a preceding detector.

   (a) For the general case show that the minimum momentum p_{min} required for a particle to emit Cherenkov radiation can be expressed as $p_{min} = \frac{m_0 c}{\sqrt{n^2-1}}$

   (b) With the above setup, determine the momentum ranges in which pions, kaons or protons can be uniquely distinguished from the other two.

[1] Boris Dolgoshein "Transition radiation detectors", Nuclear Instruments and Methods in Physics Research A326 (1993) 434-469

(c) Would removing the Aerogel B) and filling the gap with Freon 14 for a n_B=1.00049 be an improvement of the setup?

(d) Consider adding a time of flight system using two scintillators, with a time resolution of 50 ps each. What length of flight path is required to cover the low momentum range with a 3-σ separation between particle type pairs and leaving no momentum gap to the threshold Cherenkov detector?

(3 Points)

3. **NUMERICAL SIMULATION - Geant4 - Presampler**

This problem will revisit the calorimeter that was the subject of problem set 10 (see there for details), but can be solved independently if needed, with now a presampler being under study. The primary purpose of a presampler is to correct for energy loss of particles in inactive material before they enter the calorimeter. In addition the presampler is segmented into strips to provide polar angle information for e.g. photons in a full detector setup. Due to this segmentation it can also be used to achieve some separation between photons and neutral pions (which decay promptly, predominantly to two photons).

(a) Implement two additional detector components, the presampler in front of (-z direction) of the calorimeter, and a lead layer in front of the presampler to emulate 3 radiation length of inactive material (beam pipe, services, tracking, ...). The presampler is to be build from the same scintillator material as used for the rest of the calorimeter, but in strips with a depth of 10 mm and a height of 5 mm, stacking at least 20 on top of each other. For this purpose define a new G4VSolid and G4LogicalVolume analogous to "Sci", as well as G4PVPlacements of the logical volume. The same applies, with just one placement, for the inactive material. Implement a readout and study the distribution of the total energy deposited in the presampler for 1 GeV photons and pions.

(b) As a very simple method to attempt pion identification, implement the following:

- For each event, determine the maximum energy deposited into a single presampler strip.
- If there is any other strip having more than half of that energy, the event is tagged as pion induced.

An analysis targeting photons in the final state rejects all events that are tagged as pion induced. What is the resulting efficiency of selecting 1 GeV photons, and what is the fraction of 1 GeV neutral pions that survive selection due to not being tagged?

(c) What are the main factors that could explain the low pion rejection in part b)?

(5 Points)