Exercises: Particle Detectors WS 2016/17
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Problem Set No. 8

Solutions have to be handed in by Wednesday 3pm, 14.12.2016 in letter box no. 3, in the ground floor of Gustav-Mie building!

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1. **Electromagnetic Shower**
A homogeneous calorimeter is used to measure the energy of electrons or photons. The electromagnetic shower started by the incident particle can be modelled as a shower of electrons/positrons and photons using the simple assumptions:

   - Each electron/positron with an energy greater than the a critical value E_c gives up half of its energy to a bremsstrahlung photon when traveling one radiation length X_0. An electron/positron with $E < E_c$ ceases to radiate and loses all its energy locally by ionization.
   - Each photon travels one radiation length and then undergoes pair production. It should be assumed that the electron and positron each take half of the photon's energy.
     (a) How many particles are there after t radiation lengths? What is the energy per particle at that point, for an initial particle energy E_0?
     (b) Show that the maximum number of particles can be found at $t_{max} = (lnE_0/E_c)/ln2$
     (c) What is the total track length of charged particles in the shower up to t_{max}?

   [6 points]

2. **Electromagnetic calorimeter**

   The electromagnetic calorimeter for the ATLAS detector is made from roughly 2 mm thick layers of lead. Between the lead layers are 2 mm wide gaps filled with liquid argon. Lead has a Z=82, A=206, a density of 11.34 g/cm^3 and a critical energy of 10 MeV.

   - Calculate the radiation length X_0 in g/cm^2 for lead.
   - Assuming in a simple showering model where for every radiation length, the number of particles doubles and the energy of each particle is halved. Estimate the thickness that the calorimeter must have to completely contain a shower from a 200 GeV electron. (Interactions in the liquid argon can be ignored).

   [4 points]

3. **Electrons in a lead fluoride calorimeter**
Electrons of energy 734 MeV hit a Lead Fluoride (PbF_2) calorimeter (X_0=0.93 cm, density=7.77 g/cm^3, E_c=9.04 MeV). Using the usual simplified model for the shower development, calculate

   - the expected number of positrons after 4 cm.
   - What is the average positron energy at this depth?
   - At which depth do you expect the shower maximum to be?
   - How many charged particles are present in the shower at that point?

   [4 points]