Exercises Series 2

1. In the Pierre Auger Observatory the surface detectors are composed by Water Cherenkov tanks with 12 tons of water and 1.2 m of height. These detectors are able to measure the light produced by charged particles crossing them. Consider one tank crossed by a single vertical muon. The refraction index of the Water is $n \approx 1.33$ and can be in good approximation considered constant for all the relevant photons wavelengths. ($\rho_{water} \approx 1\,\mathrm{gcm}^{-3}$)

a) Determine the minimum energy of a muon in order that Cherenkov light will be emitted inside the tank.

b) If such muon has an energy of 5 GeV determine:

   i. The number of Cherenkov photons emitted along the muon trajectory inside the tank as well as the emission angle of the photons, for photons produced within energies $E \in [3; 4]\,\mathrm{eV}$ ($\lambda \in [309; 412]\,\mathrm{nm}$).

   ii. The energy lost by ionization and compare it with the energy lost by Cherenkov emission. Consider that the mean energy loss rate for water is somewhere between the helium gas and carbon.

c) Evaluate the probability of a muon to decay inside of the tank as a function of its velocity, β. Determine the probability for the limits when $\beta \to 0$ and $\beta \to 1$.

d) Discuss the experimental signature which may indicate that the muon had decayed.

2. What gain would be required from a photomultiplier in order to resolve the signal produced by three photoelectrons from that due to two or four photoelectrons? Assume that the fluctuations in the signal are described by Poisson statistics, and consider that two peaks can be resolved when their centers are separated by more than the sum of their standard deviations.

3. Electromagnetic calorimeters have usually 20 radiation lengths of material. Calculate the thickness (in cm) for a calorimeters made of of BGO, PbWO4 (as in the CMS experiment at LHC), uranium, iron, and lead. Take the radiation lengths from the Particle Data Book.

4. Consider a circular synchrotron of radius R0 which is capable of accelerating charged particles up to an energy E0. Compare the radiation emitted by a proton and an electron and discuss the difficulties to accelerate these particles with this technology.