Problem set for the lecture

Particle Detectors, WS 2015/16

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Problem set 4

Deadline: Thursday November 19, 10am

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

1. **Ionization Chamber 1**

   A minimum ionizing particle traverses a detector consisting of a parallel-plate capacitor filled with argon gas, with a distance $D = 8$ mm between the plates and a potential difference $V_0 = 1.6$ kV. The particle passes perpendicular through both plates.

   (a) How many electron-ion pairs are created, with the density of argon gas being $\rho = 1.66 \cdot 10^{-3}$ g/cm^3 and the energy required to create one pair $W = 26$ eV, assuming an energy loss of $dE/dX = 1.5$ MeV$\cdot$cm^2/g? How many electron-ion pairs would be created in liquid argon (density $\rho = 1.4$ g/cm^3)?

   (b) What are the respective drift velocities for positive ions, with mobilities being $\mu^+ = 1.7$ cm^2/(Vs) in gas and $\mu^+ = 0.5 \cdot 10^{-3}$ cm^2/(Vs) in the liquid? For comparison the drift velocity of electrons is about $v^- = 0.3$ cm/μs in both gaseous and liquid argon.

   (c) What is the average number of ions in the ionization chamber as a function of the rate of incident particles? To simplify assume all particles hit the chamber as given above. For high rates, what is the dependency of the ion density on the distance to the anode? What happens if the rate of incident particles is very high?

   (3 Points)

2. **Ionization Chamber 2**

   Again a minimum ionizing particle traverses a gas filled detector consisting of a parallel-plate capacitor, with a distance D between plates. The electric field is assumed to be too small to cause secondary ionization, and this time assume the particle to move parallel to the plates.

   (a) Please derive an equation for the voltage signal $\Delta V = V - V_0$ caused by the movement of the electrons, depending on the number of electron-ion pairs N, the capacitance C and the distance x_0 of the incident particle to the anode, using the

Ansatz of the energy equation for the capacitor:

$$\frac{1}{2}CV^2 = \frac{1}{2}CV_0^2 - N\int_{x_0}^{x} qE(x)dx$$

Assume $\Delta V << V_0$.

(b) What is the total voltage signal following from (a) (electrons and ions)?

(c) As seen, the magnitude of the signal component caused by electrons and hence, due to the difference in drift velocity of electrons and ions, signal characteristics in the parallel-plate detector strongly depend on the trajectory of the incident particle. Show that a cylindrical capacitor consisting of a thin wire anode (radius r_i) in the centre of a cylinder with radius r_a is an improvement in signal uniformity over the parallel plate model, using $E(r) = U_0/(r \cdot \ln(r_a/r_i))$ and the above energy equation. What is in general the ratio of signal components caused by the electrons to the ions, and specifically for $r_a/r_i = 10^3$ and $r_0 = r_a/2$?

(4 Points)

3. **Proportional Counter**
An argon gas-filled cylindrical capacitor, with an anode wire of radius $r_i = 25\,\mu$m and an outer radius of $r_a = 1$ cm, is this time operated as a proportional counter, with a voltage of 2 kV.

(a) Assume that secondary ionization starts to play a role when on average an electron gains the energy $W = 26$ eV required to create another electron-ion pair between two collisions with gas atoms. Given the mean free path $\lambda = 2.7\mu$m, what fraction of the detector volume contributes to the proportional gas multiplication?

(b) Considering the result of (a), explain whether the signal component from electrons or ions is typically expected to dominate in a simple proportional counter.

(c) After what ion drift length does the signal reach half of its maximum? For simplicity assume all ions to be created at r_i and the gas amplification being very high.

(3 Points)