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Particle Detectors

Particle Properties

1. Charge
2. Mass
3. Spin
4. Magnetic moment
5. Life time
6. Branching ratios etc.

What we expect form a detector

1. Tracking
2. Momentum analysis
3. Particle identification

Ionization Detectors

Based on collection of ions and electrons. A charged particle may cause

1. Excitation

$$X + q \longrightarrow X^{*} + q$$

2. Ionization

$$X + q \longrightarrow X^{+} + q + e$$

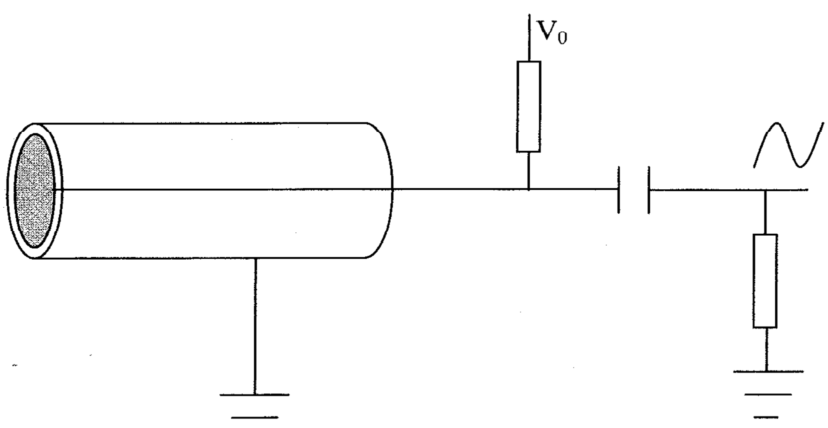

Figure 1: Basic construction of a simple gas ionization detector.

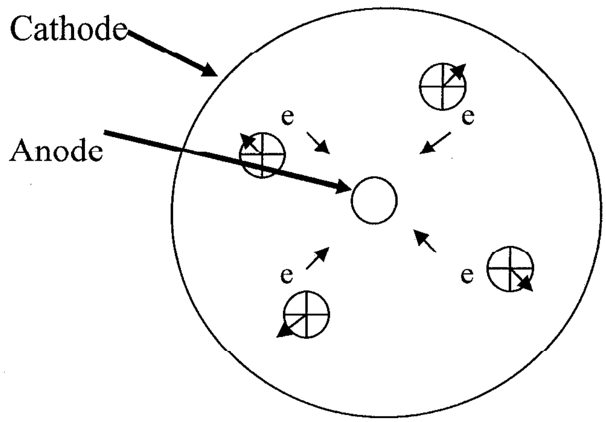

Figure 2: Cross section of the ionization detector.

The accelerated electrons will create more electron ion pairs.

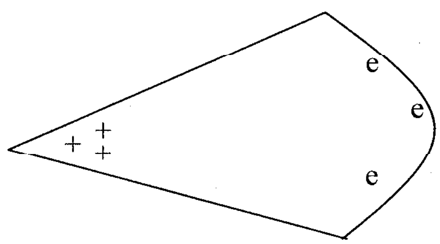

Figure 3: Avalanche formation.

The induced voltage $V(t) = -\frac{q}{4\Pi\varepsilon}\ln\left(1+\frac{\mu C V_0}{\Pi\varepsilon a^2}t\right)$

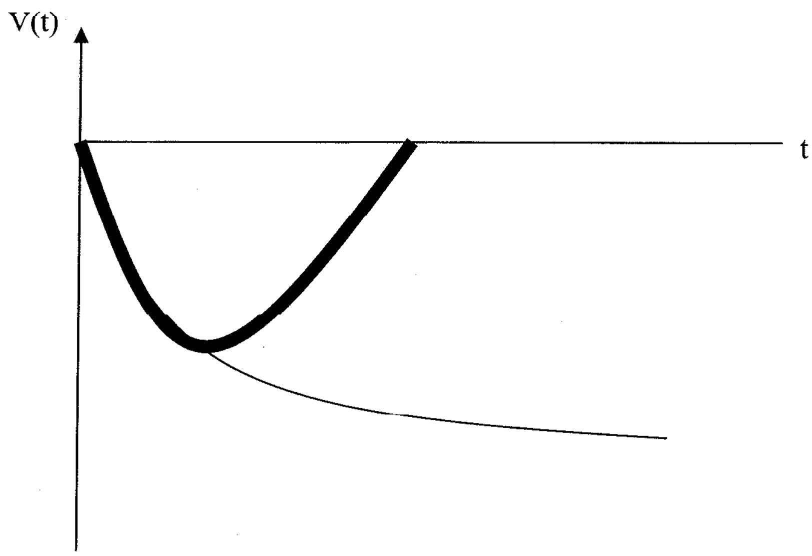

Figure 4:Pulse signal from a proportional counter.

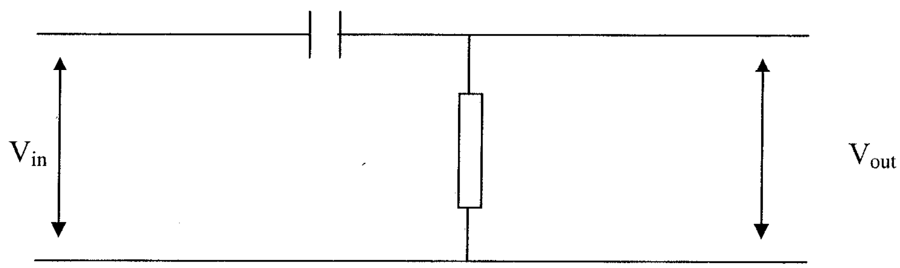

Figure 5: Differentiating RC circuit.

Properties of the filling gas

1. Low working voltage
2. High gain
3. Good proportionality

Calorimeters

Used to measure energy, position, direction and nature of primary particles. Calorimeters are blocks of matter used to degrade energy of the incident particle using ionization and excitation.

Radiation length X_0 = Length at which the initial energy drop by a factor 1/e.

$$X_0 \approx 180 \frac{A}{Z^2}$$

H_2	63.05
Pb	6.37
U	6.00

Table1: Radiation lengths of certain materials.

Electromagnetic Calorimeters

The two major contributions for the energy loss of a incoming particle through EM interactions

1. Ionization losses
2. Bremsstrahlung process (loss of energy due to photon emission)

Ionization cross section $\alpha\ Z_{Material}$
Bremsstrahlung cross section $\alpha\ Z^2_{Material}$

Electromagnetic showers

Simple model by Heitler

Assumptions

1. Each electron with $E > E_C$ travels one radiation length and gives up half of it's energy to a bremsstrahlung photon.
2. Each photon with $E > E_C$ travels one radiation length and under go pair production with each created particle receiving half of the energy of the photon.
3. Electrons with energy less than E_C cease to radiate and lose their energy through collisions.
4. Neglect ionization losses when $E > E_C$.

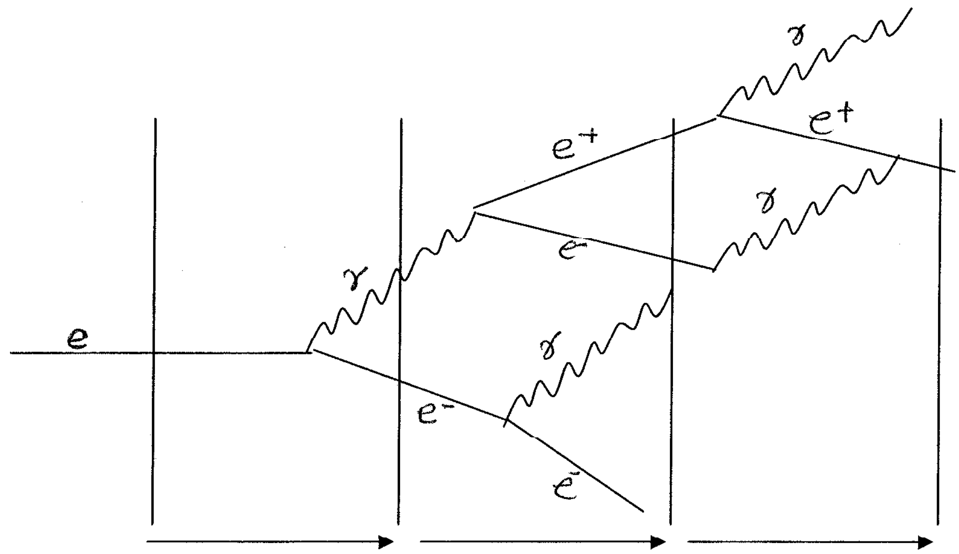

Figure 6: Heitler model.

After t radiation lengths number of particles $N(t) = 2^t$

$$N(t) = e^{t \ln 2}$$

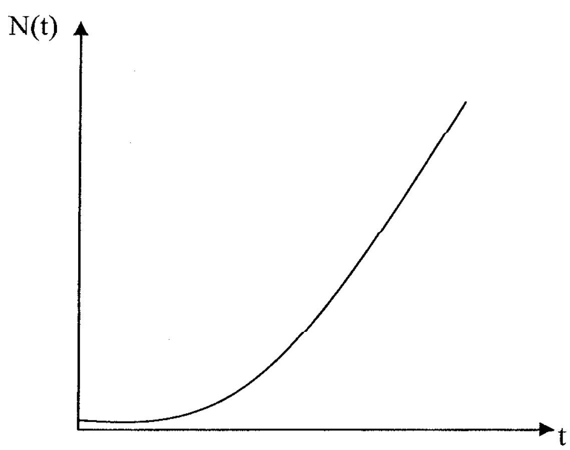

Figure 7: The plot of N(t) vs t

The average energy of shower particle at depth t = $E(t)= E_0/2^t$

Maximum number of particles created in the shower $N_{max} = \frac{E_0}{E_C}$

Number of particles in the shower that have energy greater than E\`

$$N(E>E') \approx \frac{E_0}{E'}\frac{1}{\ln 2}$$

Sum of all the track lengths of all charged particles in the shower

$$L = \frac{2}{3}\int_0^{t_{max}} N(t)dt = \frac{E_0}{E_c}$$

Empirical formulas which are accurate in the 2 – 300 GeV range

$$t_{max} = 3.9 + \ln E_0$$
$$N_{max} = 8.46 E_0^{0.935}$$
$$L = 60.2 E_0$$

The formula of E_C for solids

$$E_c = \frac{610 MeV}{Z + 1.24}$$

Detectors

Read out method is either analog or digital. In the analog type the active substance gives out a signal proportional to the number of particles. In the digital type the active substance is divided in to fine strips. Each strip will give out a digital signal (either one or zero).

The number of particles is equal to total number of "ones".

Reference:

1. Techniques for Nuclear Particle Physics Experiments , W.R. Leo
2. Introduction to experimental particle physics , Richard C. Fernow.