

## Particle detection and detector physics

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### Instructions

Please refer to the lecture notes (based on Kolanoski & Wermes) to answer the following questions. Show your calculations and clearly state your assumptions. Use the data provided in the textbook tables where necessary (e.g., Table 7.1).

### Problem 1: Fundamental Parameters

A 5 GeV muon (a Minimum Ionizing Particle, MIP) passes through a 10 cm thick detector filled with pure Xenon (Xe) gas at Normal Temperature and Pressure (NTP).

1. Using Table 7.1 from the textbook, calculate the total number of primary electron-ion pairs created.
2. Calculate the total number of electron-ion pairs (primary + secondary) created.
3. What is the total primary charge (in femtocoulombs, fC) deposited by the muon in the gas?
4. Briefly explain why the total number of pairs is significantly larger than the primary number.

### Problem 2: Signal Formation & Gas Amplification

Consider a simple proportional counter with a cylindrical cathode of radius  $b = 1$  cm and a central anode wire of radius  $a = 25$   $\mu\text{m}$ . The counter is filled with Argon and operated with a gas gain  $G = 10^5$ .

1. An avalanche occurs very close to the anode wire. Explain why the majority ( $> 95\%$ ) of the induced signal on the anode wire is generated by the positive ions, even though the electrons are collected almost instantaneously.
2. Assuming the ion mobility in Argon is  $\mu_{ion} = 1.7 \times 10^{-4} \text{ m}^2\text{V}^{-1}\text{s}^{-1}$  (at NTP) and the applied voltage is  $V_0 = 2000$  V, calculate the approximate total drift time for an ion created at the anode wire to reach the cathode.
3. What does this long ion drift time imply for a detector (like an MWPC) operating at very high particle rates?

## Problem 3: Position Resolution

Compare the intrinsic spatial resolution of two detectors used for tracking.

1. MWPC: A Multiwire Proportional Chamber has an anode wire spacing (pitch) of  $s = 2$  mm. Assuming a particle hit is assigned to the nearest wire, what is the intrinsic spatial resolution  $\sigma_x$ ?
2. Drift Chamber: A drift chamber has a drift velocity of  $v_D = 5$  cm/ $\mu$ s and a timing resolution (from electronics and diffusion) of  $\sigma_t = 2$  ns. What is the intrinsic spatial resolution  $\sigma_x$  in this case?
3. Briefly explain the purpose of the Lorentz Angle in a TPC or drift chamber operating in a solenoidal magnetic field. What detector parameters does it depend on?

## Problem 4: LHC Detector Applications

The LHC experiments use different gaseous detector technologies for specific tasks.

1. The ALICE TPC uses an  $\mathbf{E} \parallel \mathbf{B}$  field configuration. Explain the critical advantage this provides for tracking in a high-multiplicity environment, especially given its very large drift volume.
2. The ATLAS TRT uses Xenon-filled straw tubes to separate electrons from pions. The ALICE TPC uses an Argon-based gas mix to separate pions, kaons, and protons. Contrast the physical principles these two detectors use for Particle Identification (PID).
3. Why are traditional wire chambers (MWPCs, Drift Chambers) unsuitable for the innermost tracking layers at the LHC? Describe the fundamental problem and name one MPGD technology (e.g., GEM or Micromegas) designed to solve it.

## Problem 5: Einstein's equation

A stationary, hypothetical neutral particle, the "Zeta" ( $\zeta^0$ ), decays into two charged particles: a positive muon ( $\mu^+$ ) and a negative pion ( $\pi^-$ ).

The rest masses of the particles are given below:

- $m_{\zeta^0} = 450.0$  MeV
- $m_{\mu} = 105.7$  MeV
- $m_{\pi} = 139.6$  MeV

The resulting  $\pi^-$  particle immediately enters a gas-filled **proportional counter** positioned adjacent to the decay point.

The proportional counter is filled with Argon gas. The average energy required to create an electron-ion pair in Argon (the W-value) is  $W = 26$  eV. The detector is set to an operating voltage that provides a gas multiplication factor (Gain,  $G$ ) of  $5 \times 10^3$ .

Assume the  $\pi^-$  is completely stopped within the active volume of the detector.

### **Part A: Kinematics and Einstein's Equation**

Using Einstein's mass-energy equivalence principle and the laws of conservation of energy and momentum for a two-body decay, calculate the kinetic energy of the  $\pi^-$  particle ( $K_\pi$ ) in MeV immediately after the decay.

### **Part B: Detector Physics**

Based on the kinetic energy calculated in Part A, determine the total magnitude of electric charge (in Coulombs) collected at the anode wire of the proportional counter resulting from the stopping of the  $\pi^-$ .