Indian Institute of Technology Kanpur

PHY-683 Experimental Techniques in High Energy Physics

Midsem Exam, Date: September 20, 2024

Timing: 8:00 AM to 10:00 AM | Max mark: 40

Each question carries 10 marks

1. (a) At the **LHC**, different types of particles produced in high-energy collisions are detected and analyzed based on their momentum components and pseudorapidity. Below is a table of momentum components recorded for three particles (denoted as A, B and C) in a collision event.

Particle	p_x (GeV/c^2)	p_y (GeV/c^2)	p_z (GeV/c^2)
A (Charged pion $\pi^{\pm}$)	20.0	15.0	80.0
B (Jet)	30.0	25.0	120.0
C (Photon γ)	10.0	5.0	50.0

For each of the particles A, B, and C, calculate the **transverse momentum** p_T and the **pseudorapidity** (η). The analysis selection rule requires particles to have transverse momentum $p_T < 25$ GeV/c, and LHC detectors have an acceptance range of $|\eta| < 2.5$. Determine which of the particles (A, B, or C) satisfy these criteria.

2. (a) A muon with a momentum of 500 MeV/c and a pion with a momentum of 1 GeV/c are passing through copper detector with a density of $\rho =$ 8.96 g/cm^3. The approximate value of $\frac{1}{\rho}\left(-\frac{dE}{dx}\right)_{\text{ion}}$ for the muon is 1.4 MeV g^{-1} cm^2, and for the pion, it is 1.7 MeV g^{-1} cm^2. Given that the detector has a position resolution of 20 cm, can this detector distinguish between the pion and the muon purely by measuring the track length (distance travelled)?

3 (a) The appearance probability for neutrino oscillation is given by $P(\nu_\alpha \to \nu_\beta)$ and disappearance probability is $P(\nu_\alpha \to \nu_\alpha)$, where α, β, are neutrino flavors. Assuming CPT conservation, explain CP violation in neutrino sector **cannot** be measured by disappearance experiments.

(b) Using one mass scale dominance ($m_1 \sim m_2$) and the following parametrization, explain how one can get two flavor probability equations. What kind of experiments are useful to measure these all the mixing angles and mass-squared difference parameters?

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = R(\theta_{23})R(\theta_{13}, \delta)R(\theta_{12}) \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

4. (a) The charged pion decays almost 100% of the time into a muon and a muon-type neutrino:

$$\pi^+ \to \mu^+ + \nu_\mu$$

In the reference frame where the parent pion is at rest, compute the energy E_μ and the absolute value of the momentum p_μ of the muon as functions of the muon mass m_μ, the charged pion mass m_π and the muon neutrino mass m_ν. Additionally, numerically evaluate the relative change in the muon momentum between the cases where $m_\nu = 0$ and $m_\nu = 0.1$ MeV. Also, comment a detector which is able to measure muon momentum from pion decay at the level of 10^{-6} (resolution). Can this detector be used to place limits on the mass of muon neutrinos?

<u>Useful formula and constants</u>

Range, $R = \frac{1}{\rho}\int_0^T \frac{dT}{-\frac{1}{\rho}\left(\frac{dE}{dx}\right)_{\text{ion}}}$, where T is the kinetic energy.

$m_\mu = 105$ MeV/c^2, $m_\pi = 140$ MeV/c^2