Indian Institute of Technology Kanpur

PHY-683 Experimental Techniques in High Energy Physics

Endsem Exam, Date: November 20, 2023

Timing: 5.30 PM to 8.30 PM — Max marks: 90

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1. (a) How does the oscillation of neutrinos change when traveling through a constant density of matter? Get the expression for the modified mixing parameters in this context. **(7)**

   (b) Using one mass scale dominance ($m_1 \sim m_2$) and the following parametrization, get two flavor probability equations for $P(\nu_\mu \rightarrow \nu_\mu)$:

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

   What is the leading order term in oscillation frequency and amplitude? What kind of experiments are useful to measure these all the mixing angles and mass-squared difference parameters? **(3)**

2. (a) What is the underlying working principle of gaseous detectors? Furthermore, elaborate on the distinct operational regions related to the applied voltage. **(6)**

   (b) Describe the concept of radiation length (X_0) of a material and explain the Molière radius (R_M). **(4)**

3. (a) Show that for a relativistic particle, the fractional change in total energy of a particle and the fractional change in the particle momentum are related by the relation

$$\frac{dp}{p} = \frac{1}{\beta^2}\frac{dE}{E}$$

   (4)

   (b) Write down the expressions for Mandelstam variables s, u, and t. Show that

$$s + u + t = m_1^2 + m_2^2 + m_3^2 + m_4^2$$

   (2)

   (c) A medical researcher intends to use the mean of a random sample of size $n = 120$ to estimate the mean blood pressure of women in their fifties. Suppose the researcher collects the sample and finds $\bar{x} = 141.8$ mm (Hg). Based on experience, he knows that $\sigma = 10.5$ mm (Hg). Find a 98% confidence interval for the mean blood pressure of all women in their fifties. **(4)**

4. (a) Explain how parity violation is explained in the decay $^{60}_{27}\mathrm{Co} \rightarrow\ ^{60}_{28}\mathrm{Ni} + e^{-} + \bar{\nu}_{e}$? (The spin of Co is 5, the spin of Ni is 4.) **(7)**

   (b) Explain why charged leptons do not oscillate. **(3)**

5. (a) Using pure classical arguments, calculate the energy loss per unit distance, $\frac{dE}{dx}$, for a massive, charged particle as it traverses a material. **(7)**

   (b) For a silicon tracking detector, the readout strips are 5 μm apart. What is the position resolution for such detectors? **(3)**

6. (a) In a test for a disease with an efficiency of 100 % and with a false positive rate of 1 %. Suppose we know that the disease occurs in the population with a rate of 0.1 %. What is the probability that you have the disease if the test results are positive? **(5)**

   (b) What are the fundamental principles of Bayesian and frequentist philosophies in statistical interpretation. Provide an example illustrating each approach. **(2)**

   (c) If an experiment is expected to observe 100 events, but upon measurement, 143 events were recorded, and a new hypothesis suggests the presence of a new particle. How would you calculate the test significance for the emerging signal? **(3)**

7. (a) For any detector, the calorimetric energy resolution of the detector can be modeled by

$$\frac{\sigma}{E} = \frac{A}{\sqrt{E}} \oplus \frac{B}{E} \oplus C$$

   Explain each term and the origin of their functional dependencies. **(5)**

   (b) What is Cherenkov radiation? Get an expression for Cherenkov angle for a charged particle moving in a medium of refractive index n. **(5)**

8. (a) Explain the variance and bias of estimators. Calculate the maximum likelihood estimator (MLE) for an exponential distribution: $f(t;\tau) = \frac{1}{\tau} e^{-\frac{t}{\tau}}$. **(5)**

   (b) How do you graphically identify the variance of parameters estimated using a maximum log-likelihood estimation method? Note that according to the Information Inequality (RCF), $V[\hat{\theta}] = \left(\frac{-1}{\frac{\partial^2 \ln L}{\partial \theta^2}}\right)_{\theta=\hat{\theta}}$. **(5)**

9. (a) Get an expression for the total number of particles in a shower cascade initiated by photons and electrons. Demonstrate that this expression is equivalent to measuring the total energy of the particles in the cascade. **(7)**

(b) The radiation length of lead (A = 207, ρ = 11.3 g/cm^3) is 5.6 mm. What is the absorption coefficient and the cross-section for e^+e^- pair production from high-energy photons? **(3)**