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Experimental physics Vb (particle and astro-physics)

Exercise 03

Task 1 *Time-of-flight system* (4+2=6 points)

Consider a time-of-flight system consisting of two scintillator panels at a distance L. Their light signal is detected by photo multipliers. Each of the two scintillators determines the time of a particle crossing with a time resolution of σ_t. The momenta of the crossing particles are measured independently by a spectrometer and are assumed to be known.

a. Derive an equation for the maximum momentum up to which two particles with masses m_1 and m_2 can be separated with a statistiscal significance of four standard deviations. Neglect terms of $\mathcal{O}(m^4/p^4)$.

b. Up to which momentum (in GeV) can charged pions and kaons be separated with a significance of 4σ for $L = 1\,\mathrm{m}$ and $\sigma_t = 100\,\mathrm{ps}$?

Task 2 *Cherenkov detector* (4+2+3=9 points)

In a ring imaging Cherenkov counter, Cherenkov photons are radiated inside a medium of refractive index n and are imaged by an optical setup to form a ring. The Cherenkov angle θ_c can be determined from the radius of the ring.

a. Determine the mass resolution σ_m of the detector for a given absolute momentum $|\vec{p}|$ as a function of the angular resolution $\sigma(\theta_c)$ of the detector.

b. Consider two particles with given momentum but different masses m_1 and m_2. Show that the number of standard deviations to which the detector can separate between the two particles is given by

$$N_\sigma = \frac{\Delta m}{\sigma_m} = \frac{|m_1^2 - m_2^2|\beta^2}{2|\vec{p}|^2\sigma(\theta_c)\sqrt{n^2\beta^2 - 1}}.$$

c. Calculate the interval of momenta for which a detector using C_5F_{12} ($n = 1{,}0017$) as radiator and achieving an angular resolution of $\sigma(\theta_c) = 2\,\mathrm{mrad}$ can separate charged pions and kaons to a significance of 3σ. You may solve the relevant equation numerically or using a suitable approximation.

Task 3 *Decay to four photons* (2+2+1=5 points)

An unknown particle X decays inside a detector. The decay products are identified as four photons whose 3-momenta are measured as follows (all numbers in units of GeV):

$$\vec{p}_0 = (0.266, 0.0879, -0.0486)$$
$$\vec{p}_1 = (0.78, -0.185, -0.0696)$$
$$\vec{p}_2 = (0.213, 0.105, 0.0791)$$
$$\vec{p}_3 = (0.153, -0.00798, 0.0391)$$

a. Identify the particle X.

b. Which decay mode has been observed here? To which particles did X decay here? Examine which of the four photons result from the decays of each of the particles in the intermediate state.

c. Which kinetic energy did the particle X have before its decay?

Task 4 *Particle decays* (5 points)

For each of the following decay modes, state if it is allowed or by which conservation law it is forbidden. Assume that the strangeness may change by ± 1 in decays mediated by the weak interaction.

a. $\mu^- \to e^- \bar{\nu}_e \nu_\mu$

b. $\mu^- \to e^- \gamma\gamma$

c. $\mu^+ \to e^+ \bar{\nu}_e \nu_\mu$

d. $K^+ \to \pi^+ \pi^0 \pi^-$

e. $K^+ \to \pi^+ \pi^+ \pi^+ \pi^- \pi^-$

f. $\Lambda \to \pi^+ \pi^-$

g. $\Lambda \to p \pi^- \gamma$

h. $\Lambda \to p \mu^- \bar{\nu}_\mu$

i. $\Omega^- \to \Sigma^- \pi^+ \pi^-$

j. $\Sigma^+ \to p$