Massachusetts Institute of Technology

Department of Physics

Course: 8.701 – Introduction to Nuclear and Particle Physics
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Discussion Problems

from recitation on **December 3rd, 2020**

Problem 1: Scintillator counter

Consider two particles with masses m_1 and m_2 and the same momentum p. Evaluate the difference Δt between the times taken to cross a distance L. Suppose we have two scintillator counters that measure Δt with a resolution of 300 ps. How large must L be to distinguish π and K of 4 GeV momentum with two standard deviations?

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Consider the difference in energy between particles.

$$E_i^2 = p^2 + m_i^2$$
$$\beta_i = p/E_i = p/\sqrt{p^2 + m_i^2}$$
$$t_i = L/\beta_i = \frac{L}{p}\sqrt{p^2 + m_i^2}$$
$$\Delta t = \frac{L}{p}\left(\sqrt{p^2 + m_1^2} - \sqrt{p^2 + m_2^2}\right)$$

With a resolution of 300ps, $2\sigma = 600$ps.

$$m_\pi = 140 \text{ MeV}$$
$$m_K = 494 \text{ MeV}$$
$$p = 4 \text{ GeV}$$
$$L(/c) = (600 \text{ ps}\left(\frac{4000 \text{ MeV}}{\sqrt{(4000 \text{ MeV})^2 + (140 \text{ MeV})^2} - \sqrt{(4000 \text{ MeV})^2 + (494 \text{ MeV})^2}}\right)$$
$$L = 25.8 \text{ m}$$

Problem 2: Syncrotron radiation

Calculated the energy loss per turn for a circular collider due to syncrotron radiation. Assume an electron-positron collider with a center-of-mass energy of 200 GeV and a proton-proton collider of 14 TeV both with radius $R = 4.3$ km.

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Synchrotron radiation loss per turn can be quantified:

$$\begin{aligned}\Delta E &= \frac{4\pi}{3}\frac{\alpha\hbar c}{R}\gamma^4 \\ &= \frac{4\pi}{3}\frac{1}{137}\frac{197\text{MeV}\cdot\text{fm}}{R(\text{km})\cdot 10^{18}(\text{fm/km})}\left(\frac{E}{m}\right)^4\end{aligned}$$

First, for the 200 GeV electrons,

$$E = 100 \text{ GeV}$$
$$m = 0.511 \text{ MeV}$$
$$\Delta E = \frac{8.83}{R \text{ (km)}} \times 10^3 \text{ MeV}$$
$$\Delta E = 2.057 \text{ GeV}$$

if you assume R = 4.3km, like the LEP ring.

Second, for the protons,

$$E = 7 \text{ TeV}$$
$$m = 0.94 \text{ GeV}$$
$$\Delta E = \frac{18.55}{R \text{ (km)}} \times 10^{-3} \text{ MeV}$$
$$\Delta E = 4.3 \text{ keV}$$

if you assume R = 4.3km, like the LHC.

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