Tutorial 3

June 2, 2017

"Tests des Standardmodells der Teilchenphysik"

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SS 2017

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Part 1: Neutral Kaon Systems and Strangeness Oscillations

Neutral Kaons are produced copiously in strong interactions, decay via the weak interaction.

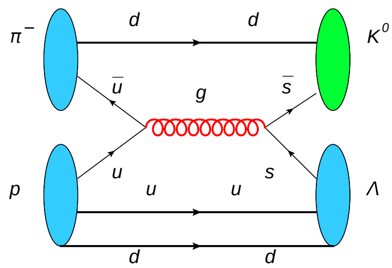

Figure 1: Neutral kaon production.

Explain how the dominance of one of the following four reactions can be used to produce a pure neutral kaon beam, that is uncontaminated by the presence of its antiparticle:

$$\pi^- \, p \to (\Lambda^0 \text{ or } K^0)(\bar{K}^0 \text{ or } K^0) \ . \tag{1}$$

Consider now the decays of a beam of neutral Kaon-meson states $K^0(d\bar{s})$. The decays to pions occur in states of definite CP. Assuming CP is conserved in the decay, we can express the K^0 states in terms of states $|K_L\rangle$ and $|K_S\rangle$

$$|K^0\rangle = \frac{1}{\sqrt{2}}\left(|K_L\rangle + |K_S\rangle\right)$$
$$|\bar{K}^0\rangle = \frac{1}{\sqrt{2}}\left(|K_L\rangle - |K_S\rangle\right) \ .$$

$|K_L\rangle$ and $|K_S\rangle$ are states with definite lifetimes $\tau_L \equiv \frac{1}{\Gamma_L}$ and $\tau_S \equiv \frac{1}{\Gamma_S}$, and dinstict rest energies $m_L c^2 \neq m_S c^2$. Hence from the point of view of decays to pions, a beam is a linear combination of CP eigenstates; a rapidly decaying CP-even component and a long-lived CP-odd component. Therefore, one would expect to see predominantly two-pion decays near start of beam and predominantly three pion decays further downstream.

Let us see how this works algebraically. At a time $t = 0$, a meson is produced in the state

$$|\Psi(t = 0)\rangle = |K^0\rangle \tag{2}$$

Let the probability of finding the system in state $|\bar{K}^0\rangle$ at a later time t be $P_0(t) = P(K^0_{t=0} \to K^0_t)$, and that finding the system in state $|\bar{K}^0\rangle$ at the same time t be $\bar{P}_0(t) = P(K^0_{t=0} \to \bar{K}^0_t)$.

Find an expression for the difference $P_0(t) - \bar{P}_0(t)$ in terms of Γ_S, Γ_L, m_S and m_L, neglecting the effects due possible CP violations. As we can see, a state that was initially a K^0 evolves with time into a mixture of K^0 and $\bar{K}^0$, that is a phenomenon often called "strangeness oscillation". Determine how this kind of oscillations between neutral kaon states occurs with a frequency given by the mass splitting $\Delta m = m_{K_L} - m_{K_S}$.

Experimentally, we find $\tau(K_S) = 0.9 \times 10^{-10}$ s, $\tau(K_L) = 0.5 \times 10^{-7}$ s and $\Delta m = (3.506 \pm 0.006) \times 10^{-15}$ GeV. The K_L mass is greater than the k_S by 1 part in 10^{16}.

Finally, calculate the ratio K_S to K_L in a beam of 10 GeV/c neutral kaons at a distance 20 m from where the beam is produced.

References

- *Modern Particle Physics*, Mark Thomson, Cambridge University Press, 2013 **Chapter 14.4**
- *Elementary Particles in a Nutshell*, Christopher G. Tully, Princeton University Press, 2011 **Chapter 6**