Flavor Physics – Exercise Sheet 6 – SomSem 2014

Discussion: 06/06 during the tutorial

Exercise 1: $K^0 - \bar{K^0}$ oscillation probability

Assuming CP invariance the observed K_S and K_L states are given by the following linear combinations of the flavor states,

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

The physical states exhibit the time-dependence $|K_{S,L}(t)\rangle = e^{-im_{S,L}t}e^{-i\Gamma_{S,L}t/2}\,|K_{S,L}\rangle$, where $m_{S,L}$ and $\Gamma_{S,L}$ are the mass and the total decay width of the state.

Derive the time dependent probability $P(K^0(t=0) \to K^0)(t)$ to observe an initial K^0 after time t as K^0 and the probability $P(K^0(t=0) \to \bar{K^0})(t)$ to observe it in the flavor-mixed $\bar{K^0}$ state. The formulae were given in the lecture.

Exercise 2: K_S–K_L interference as confirmation for CP violation

In presence of CP violation the physical states K_S and K_L decaying to CP eigenstates can interfere. For a neutral kaon which is produced at $t = 0$ as a $K^0\left(\bar{K^0}\right)$ and propagates freely in vacuum, the time-dependent decay rate to $\pi^+\pi^-$ is given by

$$\Gamma\left[K^0\left(\bar{K^0}\right)(t=0)\right](t) \propto e^{-\Gamma_S t} + |\eta_{\pi\pi}|^2\, e^{-\Gamma_L t} \pm 2\,|\eta_{\pi\pi}|\, e^{-(\Gamma_S+\Gamma_L)t/2}\cos\left(\Delta m t - \phi_{\pi\pi}\right),$$

where the $+$ $(-)$ sign applies for the $K^0\left(\bar{K^0}\right)$. The complex number $\eta_{\pi\pi} = |\eta_{\pi\pi}|\, e^{i\phi_{\pi\pi}}$ describes the CP violating amplitude ratio

$$\eta_{\pi\pi} = \frac{\mathcal{A}(K_L \to \pi\pi)}{\mathcal{A}(K_S \to \pi\pi)}.$$

a) Motivate the above formula for the time dependent decay-rate.

b) Read the attached paper: *C. Geweniger et al., Phys. Lett. 48B (1974) 487.*

- Explain the selection of the $K^0 \to \pi\pi$ events.
- How is the proper-time distribution in Figure 4 obtained.
- How do the authors finally obtain $|\eta_{\pi\pi}|$ and the phase $\phi_{\pi\pi}$.

To better understand the detector layout, a second paper describing the apparatus is also added *C. Geweniger et al., Phys. Lett. 48B (1974) 483.*