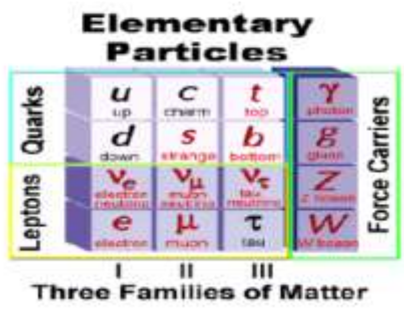
NEUTRAL KAONS

Faridah Mohamad Idris[1,2], Wan Ahmad Tajuddin Wan Abdullah[2], Zainol Abidin Ibrahim[2].
[1]Malaysian Nuclear Agency, Bangi, 43000 Kajang, Selangor D.E. Malaysia
[2]National Centre for Particle Physics (NCPP), Universiti Malaya, 50603 Kuala Lumpur

Abstract. In charge conjugate and parity violation (CPV) study, neutral kaons K_S^0 and K_L^0 gives an interesting comparison. Even though both have slight difference in mass, the latter has greater phase space than the former and shows that it violates CPV through its decay into $\pi^{\pm}$. This paper reviews aspects of the CPV violations of these neutral kaons .

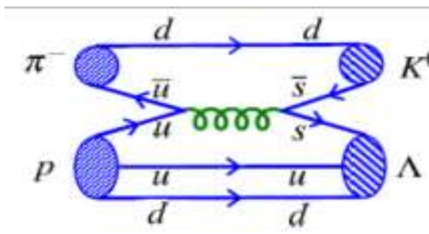
Introduction. Neutral Kaons K_S^0 and K_L^0 are mesons with branching ratio K_S^0 (50%), K_L^0 (50%): They represent symmetric and antisymmetric mixtures of the quark combinations down-antistrange ($d\bar{s}$) and antidown-strange ($\bar{d}s$). The quark mixing in these combinations involves the exchange of two W bosons. They decay via weak interaction and are used in the study of charge conjugate and parity violation (CPV).



Standard Model of Particle Physics

$$\pi^-(d\bar{u}) + p(uud) \rightarrow \Lambda(uds) + K^0(d\bar{s})$$
$$\pi^+(u\bar{d}) + p(uud) \rightarrow K^+(u\bar{s}) + \bar{K}^0(s\bar{d}) + p(uud)$$

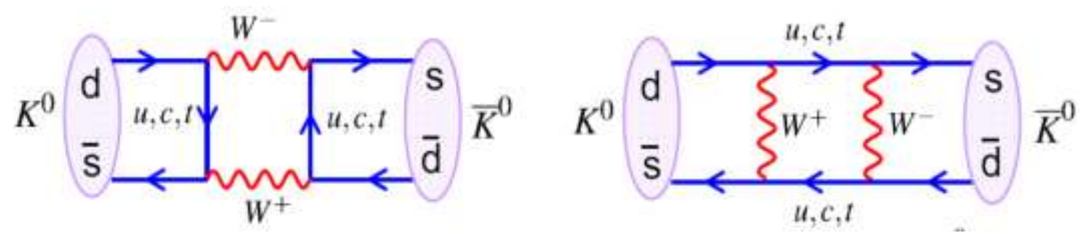
Neutral Kaons produced in strong interaction.



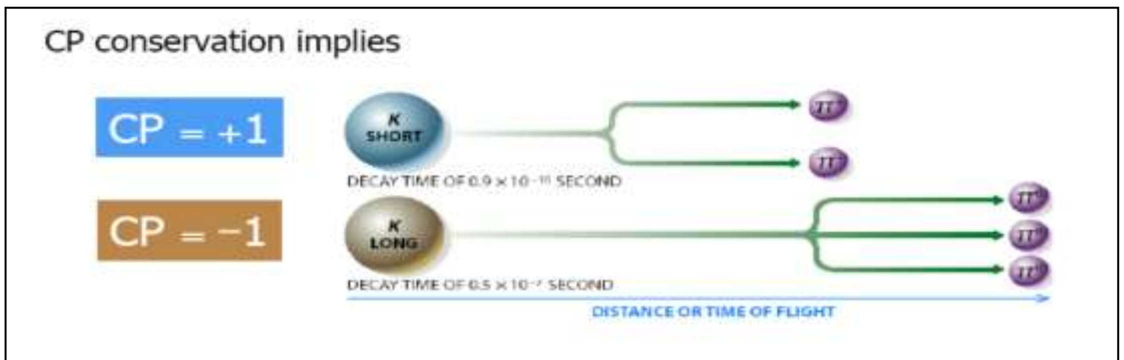
Feynman diagram of Neutral Kaons in strong interaction.

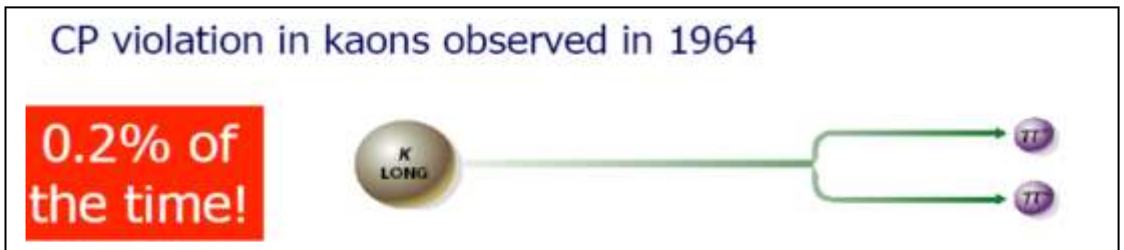
Table 1. properties of Neutral Kaons

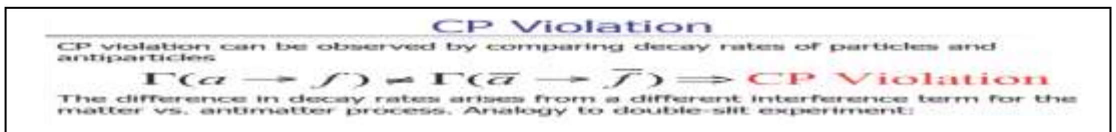
Neutral Kaons	K-zero-short: K_S^0	K-zero-long: K_L^0
quark combinations	$\frac{\psi(d\bar{s})+\psi(\bar{d}s)}{\sqrt{2}}$	$\frac{\psi(d\bar{s})+\psi(\bar{d}s)}{\sqrt{2}}$
Lifetime	$8.95\times10^{-11}s$	$5.11\times10^{-8}s$
Decay length	2.6842cm	15.33m
Decay (hadronic) modes	$K_S^0 \rightarrow \pi^+ + \pi^-$ (31.69%) $K_S^0 \rightarrow \pi^0 + \pi^0$ (69.20%) $K_S^0 \rightarrow \pi^+ + \pi^- + \pi^0 (3.5\times10^{-7}$%	$K_L^0 \rightarrow \pi^+ + \pi^- + \pi^0$ (12.56%) (CP=-1) $K_L^0 \rightarrow \pi^0 + \pi^0 + \pi^0$ (19.56%) (CP=-1) $K_L^0 \rightarrow \pi^+ + \pi^- (1.98\times10^{-3}$%) (CP=+1) $K_L^0 \rightarrow \pi^0 + \pi^0 (8.69\times10^{-4}$%) (CP=+1)
Mass K^0	0.498GeV	
Mass difference	$\Delta m = m_{K_L} - m_{K_S} = 3.483\times10^{-12}\ MeV$	
Oscillation period	$T_{osc} = \frac{2\pi\hbar}{\Delta m} \approx 1.2\times10^{-9}$ s	
Ratio	K_S^0 (50%)	K_L^0 (50%)
$I(J^P)$	$\frac{1}{2}(0^-)$	$\frac{1}{2}(0^-)$
Note:	$I^G(J^P)\pi^{\pm} = 1^-(0^-)$; $I^G(J^P)\pi^0 = 1^-(0^{-+})$;	

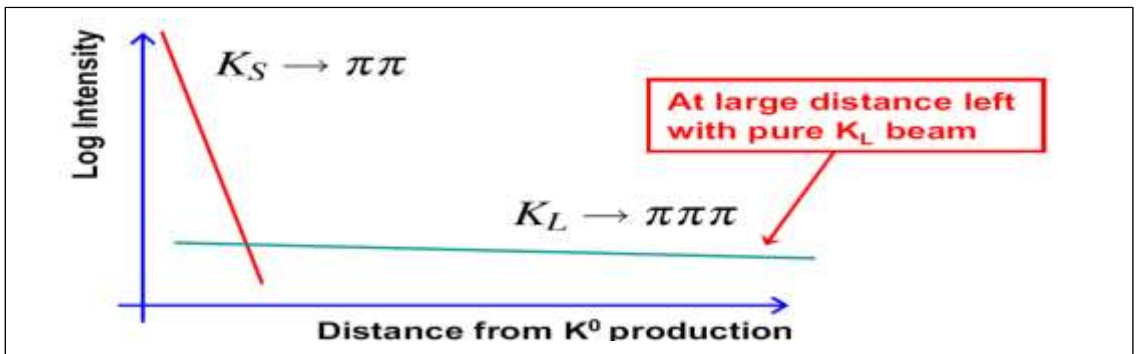


Mixing of Neutral Kaons in weak interaction









Strong eigenstates Neutral Kaon:

$K^0(d\bar{s})$ and $\bar{K}^0(s\bar{d})$ have $J^P = 0^-$

Decay of Neutral Kaons:

$$|K_0\rangle = \frac{1}{\sqrt{2}}(|K_S\rangle + |K_L\rangle)$$

CP is violated in the decay (**direct CPV**)

$$|K_L\rangle = |K_2\rangle \rightarrow |\pi\pi\rangle$$
$$\text{CP}=-1 \rightarrow \text{CP}=+1$$

$$CP = |K^0\rangle\langle\bar{K}^0| + |\bar{K}^0\rangle\langle K^0|.$$

Energy of K_S: $\omega_S = \sqrt{p^2 + m_S^2},$

Energy of K_L: $\omega_L = \sqrt{p^2 + m_L^2},$

Probability to find K_0 undecayed at time t with life time $\tau_S = 1/\Gamma_S$:

$$P(t) = e^{-\Gamma_S t}.$$
$$\psi(t) = e^{-i\omega_S t - \Gamma_S t/2}|K_S^0\rangle.$$
$$\psi(t) = e^{-i\omega_L t - \Gamma_L t/2}|K_L^0\rangle.$$

Probability of finding K_0 at time t:

$$P_{K^0}(t) = |\langle K^0|\psi(t)\rangle|^2 = \frac{1}{2}|\langle K^0|K_S^0\rangle e^{-i\omega_S t - \Gamma_S t/2} - \langle K^0|K_L^0\rangle e^{-i\omega_L t - \Gamma_L t/2}|^2$$

Decays to Two Pions:

★ $K^0 \rightarrow \pi^0\pi^0$ $\quad J^P: \quad 0^- \rightarrow 0^- + 0^-$

Decays to Three Pions:

★ $K^0 \rightarrow \pi^0\pi^0\pi^0$ $\quad J^P: \quad 0^- \rightarrow 0^- + 0^- + 0^-$

- For two pion decay energy available: $m_K - 2m_\pi \approx 220\text{MeV}$
- For three pion decay energy available: $m_K - 3m_\pi \approx 80\text{MeV}$

$|K_S\rangle = |K_1\rangle \equiv \frac{1}{\sqrt{2}}(|K^0\rangle - |\bar{K}^0\rangle)$ with decays: $K_S \rightarrow \pi\pi$

$|K_L\rangle = |K_2\rangle \equiv \frac{1}{\sqrt{2}}(|K^0\rangle + |\bar{K}^0\rangle)$ with decays: $K_L \rightarrow \pi\pi\pi$