Oscilacije stranosti

1. Sustav $K^0 - \bar{K}^0$ mezona

	S	I_3
K^+	+1	1/2
K^-	−1	−1/2
K^0	+1	1/2
$\bar{K}^0$	−1	−1/2

Gell-Mann - Nishijima relacija:

$$Q = I_3 + \frac{1}{2} Y = I_3 + \frac{1}{2} S$$

2. Produkcija K^0

$$\pi^- + p \Rightarrow K^0 + \Lambda$$

S: 0 0 +1 −1

$|\Delta S| = 0$

'jaki' proces

Produkcija $\bar{K}^0$

$$\pi^- + p \Rightarrow \bar{K}^0 + K^+ + p$$

S: 0 0 −1 1 0

$|\Delta S| = 0$

'jaki' proces

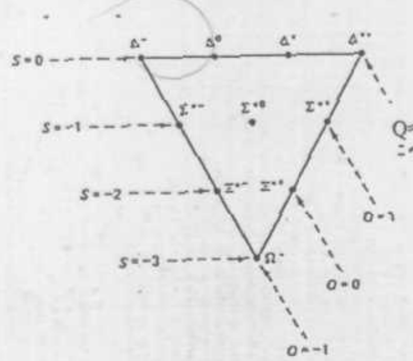
- Iz proučavanja 'jakih' procesa znademo

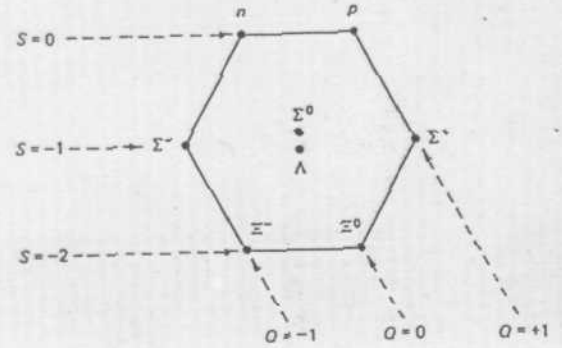
$$\hat{C}\hat{P}\,|K^0\rangle = (+1)\,|\bar{K}^0\rangle$$

$$\hat{C}\hat{P}\,|\bar{K}^0\rangle = (+1)\,|K^0\rangle$$

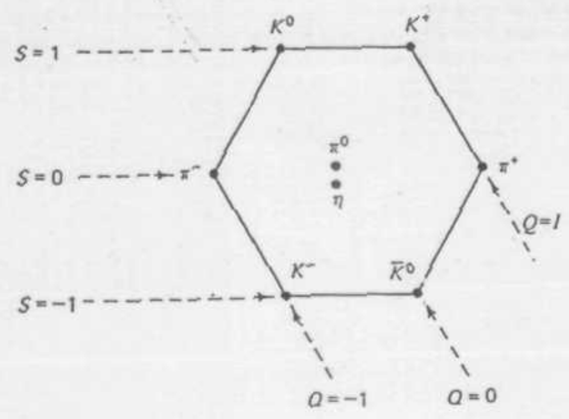
$\Rightarrow$ $|K^0\rangle$, $|\bar{K}^0\rangle$ } nisu vlastita stanja operatora $\hat{C}\hat{P}$!!

Napomena: K^0 i $\bar{K}^0$ razlikujemo po načinu produkcije!


S=0
S=−1
S=−2
S=−3
Ω⁻
Q=2
Q=1
Q=0
Q=−1


n
p
S=0
S=−1
S=−2
Σ⁰
Λ
Σ⁻
Σ⁺
Ξ⁻
Ξ⁰
Q=−1
Q=0
Q=+1

Slika 2.1.a


S=1
S=0
S=−1
K⁰
K⁺
π⁻
π⁰
η
π⁺
K⁻
K̄⁰
Q=1
Q=−1
Q=0

3. Eigenstanja operatora $\hat{C}\hat{P}$

$$|K_1\rangle = \frac{1}{\sqrt{2}}\left(|K^0\rangle + |\bar{K}^0\rangle\right)$$

$$|K_2\rangle = \frac{1}{\sqrt{2}}\left(|K^0\rangle - |\bar{K}^0\rangle\right)$$

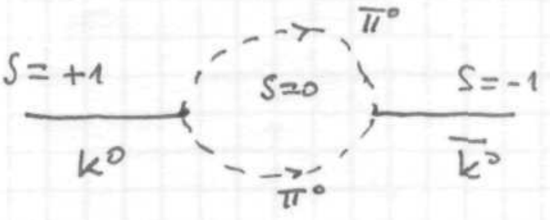
- $\hat{C}\hat{P}\,|K_1\rangle = \frac{1}{\sqrt{2}}\left(\hat{C}\hat{P}|K^0\rangle + \hat{C}\hat{P}|\bar{K}^0\rangle\right) =$
  $= \frac{1}{\sqrt{2}}\left(|\bar{K}^0\rangle + |K^0\rangle\right) = (+)\,|K_1\rangle$

- $\hat{C}\hat{P}\,|K_2\rangle = (-)\,|K_2\rangle$

$\left.\begin{array}{l}|K_1\rangle \\ |K_2\rangle\end{array}\right\}$ vlastita stanja operatora $\hat{C}\hat{P}$ $(\eta_{CP} = \pm 1)$

Napomena: $|K_1\rangle$ i $|K_2\rangle$ se razlikuju po načinu raspada

Produkcija	Raspad	Poluživot
$\lvert K^0\rangle$ $(S=1)$	$K_1 \to 2\pi$ $\eta_{CP} = +1$ (K_S^0)	10^{-10} s
$\lvert\bar{K}^0\rangle$ $(S=-1)$	$K_2 \to 3\pi$ $(\eta_{CP} = -1)$ (K_L^0)	10^{-7} s
'jaki' proces	'slabi' proces	



$|\Delta S| = 2$

'miješanje' $K^0 - \bar{K}^0$

4. $\hat{C}\hat{P}$ - narušenje u slabim interakcijama

Ako je $[\hat{H}_W, \hat{C}\hat{P}] = 0$ onda je $\hat{C}\hat{P}$ simetrija egzaktna.

- $K_1 \equiv K_S^0 \rightarrow \underbrace{\pi^+ + \pi^-}_{+1}, \underbrace{\pi^0 + \pi^0}_{+1}$, ✓ $|\Delta CP| = 0$

  $\hat{C}\hat{P}$: $+1$

- $K_2 \equiv K_L^0 \not\rightarrow \underbrace{\pi^+ + \pi^-}_{+1}, \underbrace{\pi^0 + \pi^0}_{+1}$ $|\Delta CP| = 2$

  $\hat{C}\hat{P}$: -1

- 1964. Christensen, Kronin, Fitch, Turley:

$$\frac{R(K_L^0 \rightarrow \pi^+\pi^-)}{R(K_S^0 \rightarrow \pi^+\pi^-)} = 2.27 \cdot 10^{-3} \quad (\sim 0.3\,\%)$$

malo (0.3 %) narušenje $\hat{C}\hat{P}$ - simetrije !!

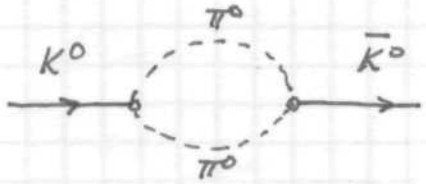
- $$\frac{R(K_L^0 \rightarrow \pi^- e^+ \nu_e) - R'(K_L^0 \rightarrow \pi^+ e^- \bar{\nu}_e)}{R(\cdots) + R'(\cdots)} = 3.3 \cdot 10^{-3}$$

- Napomena: kako je $\dfrac{R(K_L^0 \rightarrow e^+ \pi^- \nu_e)}{R(K_L^0 \rightarrow e^- \bar{\nu}_e \pi^+)} > 1$

K_L^0 raspad 'određuje' (definira) predznak naboja!

5. Oscilacije stranosti i fenomen regeneracije

- slabe sile ne čuvaju S:



$|\Delta S| = 2$

tj. u $t=0$ imamo 'čisto' stanje $|K^0\rangle$, a u $t>0$ 'miješano' stanje:

$$|K(t)\rangle = \alpha(t)\,|K^0\rangle + \beta(t)\,|\bar{K}^0\rangle$$

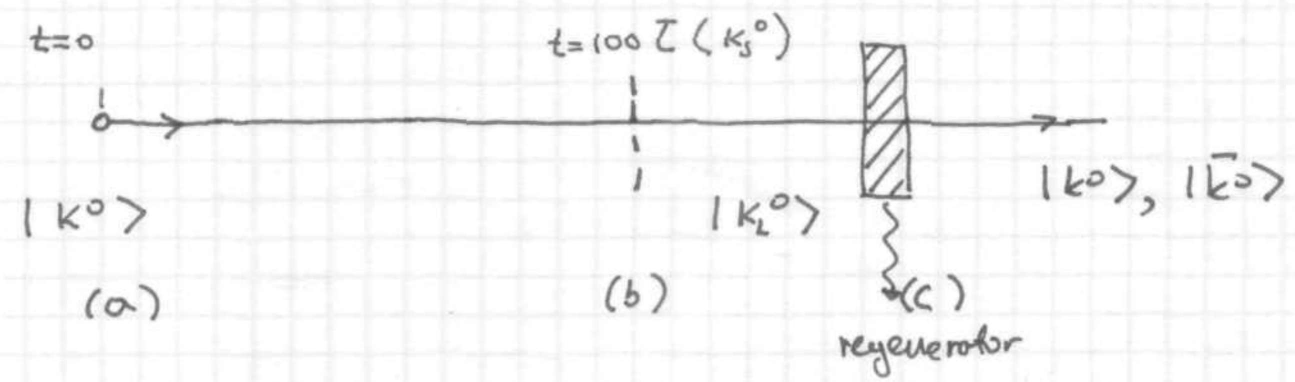
- veza između stanja koja 'vidi' slaba i jaka sila:

$$\left.\begin{aligned} |K_L^0\rangle &= \frac{1}{\sqrt{2}}\left(|K^0\rangle - |\bar{K}^0\rangle\right) \\ |K_S^0\rangle &= \frac{1}{\sqrt{2}}\left(|K^0\rangle + |\bar{K}^0\rangle\right) \end{aligned}\right\} \text{ slaba} \to \text{jaka}$$

$$\left.\begin{aligned} |K^0\rangle &= \frac{1}{\sqrt{2}}\left(|K_L^0\rangle + |K_S^0\rangle\right) \\ |\bar{K}^0\rangle &= \frac{1}{\sqrt{2}}\left(|K_S^0\rangle - |K_L^0\rangle\right) \end{aligned}\right\} \text{ jaka} \to \text{slaba}$$

$$\begin{pmatrix} |K_L^0\rangle \\ |K_S^0\rangle \end{pmatrix} = \begin{pmatrix} \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{pmatrix} \begin{pmatrix} |K^0\rangle \\ |\bar{K}^0\rangle \end{pmatrix}$$

$$\begin{pmatrix} |K^0\rangle \\ |\bar{K}^0\rangle \end{pmatrix} = \begin{pmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ -\frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{pmatrix} \begin{pmatrix} |K_L^0\rangle \\ |K_S^0\rangle \end{pmatrix}$$



(a) $t=0$: iz $\pi^- + p \rightarrow K^0 + \Lambda$ izdvoji se

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

(b) $t = 100\,\tau(K_S^0)$

$\sim 10^{-8}\,s$

komponenta $|K_S^0\rangle$ se raspadne $\left(K_S^0 \rightarrow 2\pi\right)$ (slabom silom)

i isčezne iz snopa. Ostaje samo

$|K^0\rangle \propto |K_L^0\rangle$

(c) u regeneratoru dolazi do regeneracije $\overline{K}^0$

jer: $|K_L^0\rangle \propto |K^0\rangle + |\overline{K}^0\rangle$

- $\overline{K}^0$ se detektira kroz reakciju

  $\overline{K}^0 + p \rightarrow \Lambda + \pi^+$ ('jaki' proces)

- znamo da nije K^0 jer

  $K^0 + p \rightarrow \Lambda + \pi^+$

  ne čuva S!

6. Oscilacije stranosti

- K_L^0 i K_S^0 se raspadaju u 10^{-7} i 10^{-10} s, respektivno

Parametriziramo valne funkcije ($\hbar = c = 1$)

$$\psi_{L,S}(t) = \psi_{L,S}(0) \underbrace{e^{-i m_{L,S} t}}_{\text{oscilacije}} \underbrace{e^{-\frac{1}{2}\Gamma_{L,S} \cdot t}}_{\text{raspadi}}$$

$$E_{L,S} = m_{L,S} \quad ; \quad \Gamma_{L,S} = \frac{1}{\tau_{L,S}}$$

- Intenzitet snopa:

$$I_{L,S}(t) = \psi_{L,S} \cdot \psi_{L,S}^* = I_{L,S}(0)\, e^{-\Gamma_{L,S} \cdot t}$$

- Neka u $t=0$, imamo $K^0 \propto K_L^0 + K_S^0$

u $t>0$:

$$I_{K^0} = (\psi_L + \psi_S)(\psi_L + \psi_S)^* =$$
$$= \left(e^{-\Gamma_L \cdot t} + e^{-\Gamma_S \cdot t}\right) + e^{-\frac{1}{2}(\Gamma_L + \Gamma_S) \cdot t} \cdot \cos \Delta m t$$

$$I_{K^0}(t) \propto A(t) \cdot \cos (m_S - m_L) \cdot t$$

- Eksperiment:

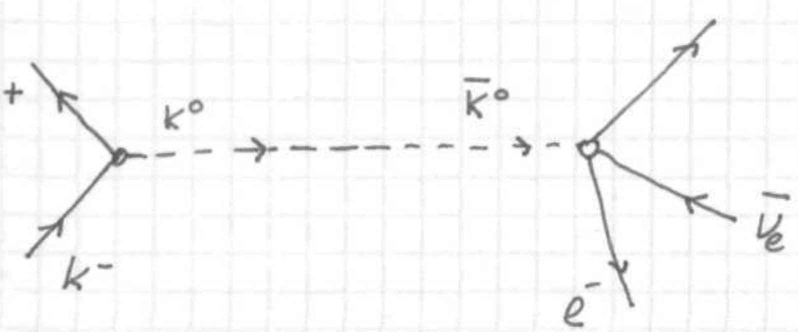
$$\Delta m \cdot t = (m_S - m_L) \cdot t = 0.5$$

$$\Delta m = 3.5 \cdot 10^{-6} \, eV$$

7. Slabe sile i vremenska asimetrija

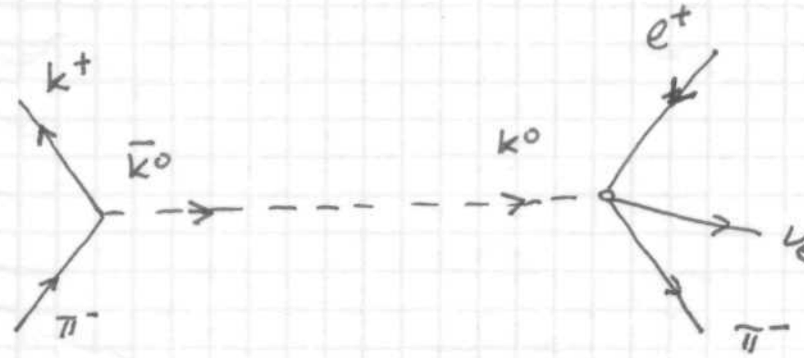
- CPLEAR eksperiment (CERN, 1998.)

(a) p, $\bar{p}$ ⟹ anihilacija



- amplituda $R(K^0 \to \bar{K}^0)$

(b) p, $\bar{p}$ ⟹ anihilacija



- amplituda $\bar{R}(\bar{K}^0 \to K^0)$

U QFT, R i $\bar{R}$ su procesi inverzni u vremenu tj. $R \overset{t \to -t}{\longleftrightarrow} \bar{R}$.

Ako slabe sile 'čuvaju' vremensku obrativost onda mora biti $R = \bar{R}$.

> Ekiperiment: $\bar{R}$ se dešava sa 0.66 % većom vjerojatnošću
>
> Slabe sile ne čuvaju T !!