Šibka interakcija

$\pi^0 \quad \tau = 8{,}4 \cdot 10^{-17}\,s$

$\pi^- \quad \tau = 2{,}6 \cdot 10^{-8}\,s$

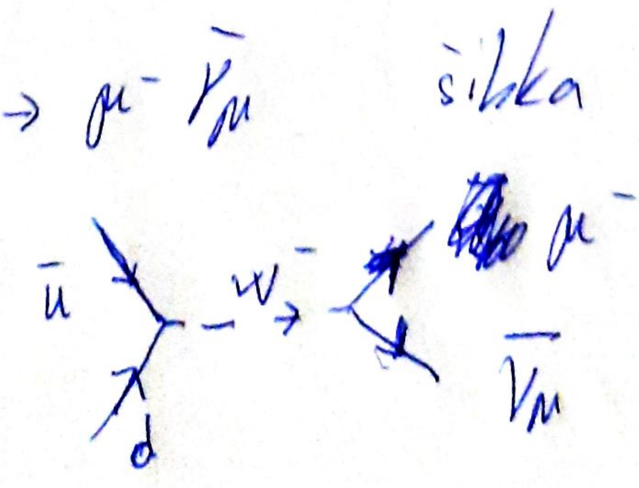
?

Razlika v τ tako velika, da mora razpad potekati preko različnih interakcij.

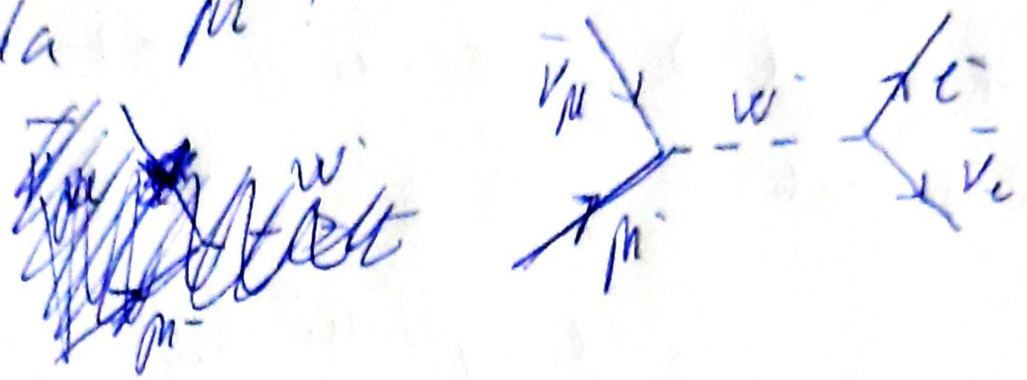
π: najlažji hadroni $\rightarrow$ razpadajo po ~~inter~~ drugih int., ne po močni.

$\pi^0 \rightarrow \gamma\gamma$ EM

$\pi^- \rightarrow \mu^- \bar{\nu}_\mu$ šibka



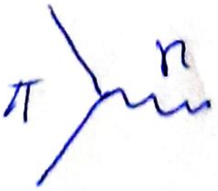
Podobno - po šibki int. - razpada μ^-:



Razlika v Z:

Šibka: $$|\mathcal{M}_W|^2 \propto \left[\frac{g_W}{(M_W c^2)^2}\right]^2$$

EM: $$|\mathcal{M}_{EM}|^2 \propto \left[\frac{g_{EM}}{q^2 c^2}\right]^2$$

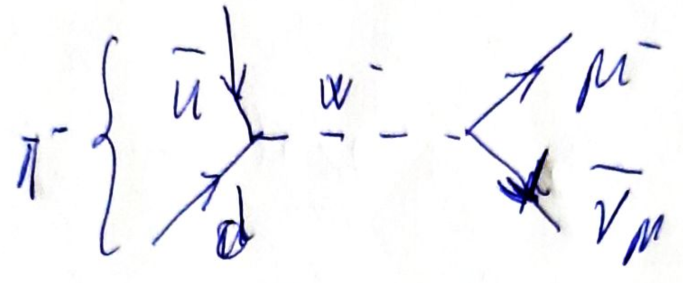


$$q^2 c^2 \sim (M_\pi c^2)^2$$

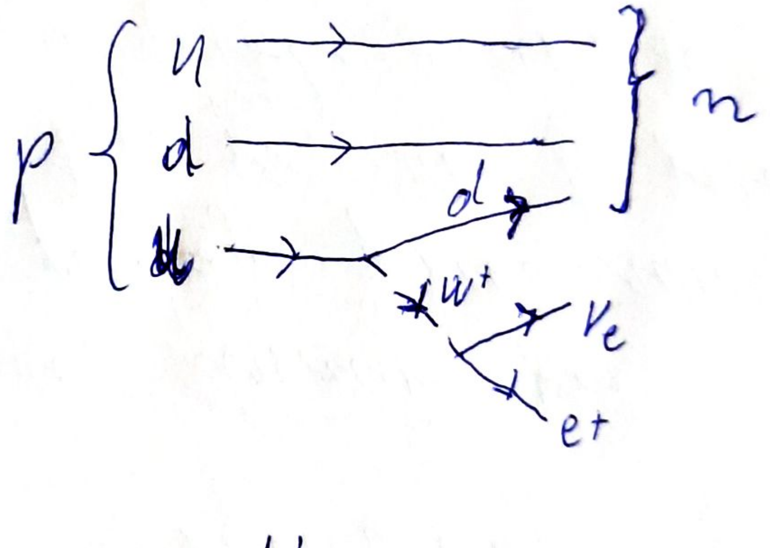
$$\frac{\tau_W}{\tau_{EM}} \propto \left|\frac{\mathcal{M}_{EM}}{\mathcal{M}_W}\right|^2 \sim \left[\frac{M_\pi c^2}{M_W c^2}\right]^2 \sim 10^{-11}$$

Šibka int. povzroča tudi jedrske razpade β:

$\pi^- \to \mu^- \bar{\nu}_\mu$



$p \to n e^+ \nu_e$



Operator parnosti

$$\hat{P}\,\psi(\vec{r}) = \psi(-\vec{r})$$

$$\hat{P}^2\psi(\vec{r}) = \hat{P}\,\psi(-\vec{r}) = \psi(\vec{r})$$

$\Rightarrow$ lastna vrednosti $\hat{P}^2$: 1

lastna — " — $\hat{P}$: ± 1

$\hat{P}$: zrcaljenje prostora
(diskretna transform.)

Če so enačbe gibanja nekega sistema invariantne na $\hat{P}$, tedaj pravimo, da se parnost ohranja, sicer je ohranitev parnosti kršena.

Operator konjugacije naboja

$$\underset{\text{delec}}{\hat{C}\,\psi} = \underset{\text{anti-delec}}{\bar{\psi}}$$

zopet $\hat{C}^2 \psi = \psi \Rightarrow$ lastne vrednosti $\hat{C}$: ± 1

(3)

Operator sučnosti

Sučnost: projekcija spina na smer gibalne količine

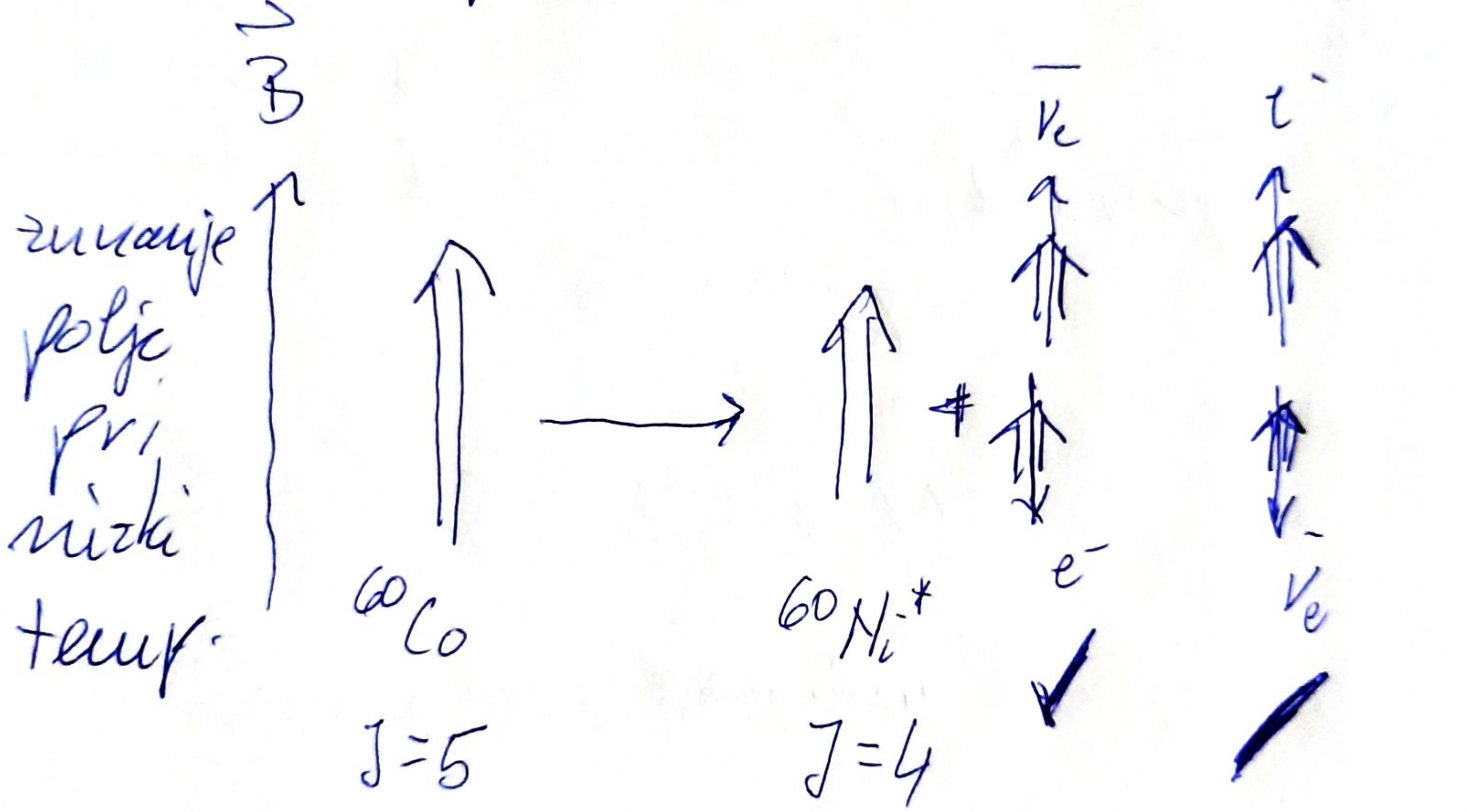
$$\hat{\Sigma} = \vec{\sigma}\,\frac{\vec{p}}{p}$$

↑ operator spina

za fermion s $\sigma = \frac{1}{2} \Rightarrow \Sigma = \pm\frac{1}{2}$

Kršitev parnosti

L. 1956 sta Tsung Duo Lee in Chen Ning Yang pregledala dotlej znane eksp. podatke o procesih preko šibke int. in postavila hipotezo, da le-ta krši ohranitev parnosti. V dogovoru z Chien Shiung Wu pridejo do eksperimenta:



→ smer gib. količ.

⇒ projekcija spina

β razpad ^{60}Co:

$^{60}Co \to {}^{60}Ni\, e^- \bar{\nu}_e$

~~ali~~ Rezultat pomeni, da šibka int. krši parnost

Zakaj?

$^{60}Co \Uparrow \qquad \downarrow e^-$ ✓

$\downarrow \vec{P}$

$^{60}Co \Uparrow \qquad \uparrow e^-$ //

(spin je aksialni vektor)

Če bi se parnost ohranjala, bi imeli enako obeh primerov.

Ostale inter. (EM in močna) ohranjajo parnost!

Rezultat ^{60}Co eksperim.

nam pove, da imamo opravka le z levosučnimi nevtrini

ν_L	$\vec{p}$	ν_R
$\longrightarrow$	$\rightarrow$	$\longleftarrow$
$\Leftarrow$		$\Leftarrow$
✓		$\not\!/$

$\bar{\nu}_R$	$\vec{p}$	$\bar{\nu}_L$
$\longrightarrow$	$\rightarrow$	$\longleftarrow$
$\Rightarrow$		$\Rightarrow$
✓		$\not\!/$

teh stanj v šibki int. (ki pa je edina, ki jo ν občutijo!) ne opazimo $\Rightarrow$

$\Rightarrow$ kršitev parnosti

To hkrati pomeni kršitev konjugacije naboja

$$\begin{array}{ccc} \nu_L & \xrightarrow{\hat{C}} & \bar{\nu}_L \\ \Leftarrow & & \Leftarrow \\ \checkmark & & // \end{array}$$

$$\begin{array}{ccc} \bar{\nu}_R & \xrightarrow{\hat{C}} & \nu_R \\ \Rightarrow & & \Rightarrow \\ \checkmark & & // \end{array}$$

V 50-ih letih so mislili (L. Landau), da se ohranja kombinirana parnost $\hat{C}\hat{P}$.

$$\begin{array}{ccccc} \nu_L & \xrightarrow{\hat{P}} & \nu_R & \xrightarrow{\hat{C}} & \bar{\nu}_R \\ \Leftarrow & & \Leftarrow & & \Leftarrow \\ \checkmark & & // & & \checkmark \end{array}$$

$$\begin{array}{ccccc} \bar{\nu}_R & \xrightarrow{\hat{P}} & \bar{\nu}_L & \xrightarrow{\hat{C}} & \nu_L \\ \Rightarrow & & \Rightarrow & & \Rightarrow \\ \checkmark & & // & & \checkmark \end{array}$$

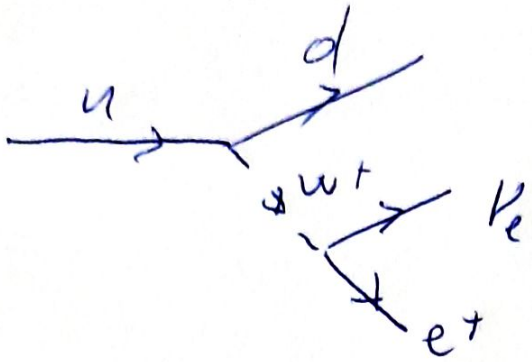
V 60-ih letih so z eksper. ugotovili, da šibka int. ne ohranja parnosti $\hat{C}\hat{P}$.

To je eden osnovnih (Saharovih) pogojev za razvoj današnjega vesolja. (o tem pri predmetu FJOD).

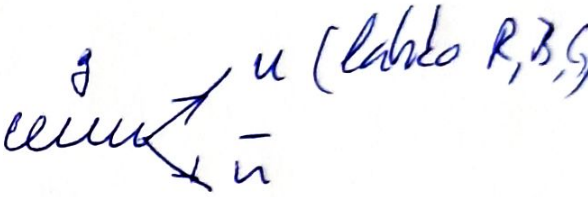
Matrika Cabibbo-Kobayashi-Maskawa (CKM)

šibka int. je edina, ki spreminja okus kvarkom.

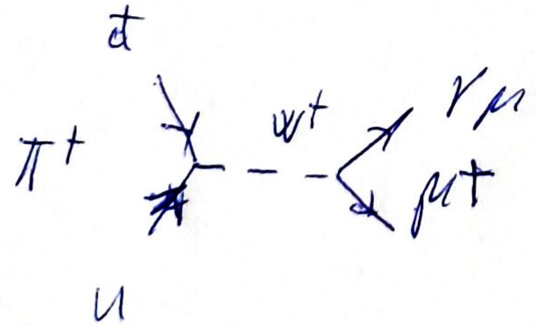
npr.



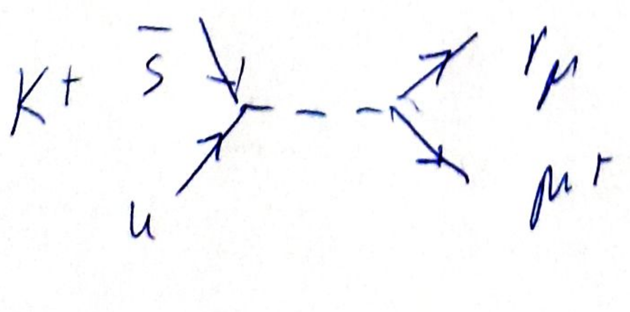
sicer



Vendar v 60-ih letih problem z



veliko bolj verjeten, kot



Nicola Cabibbo je l. 1963 (takrat so še zavedali zgolj kvarkov u, d in s) predlagal, da v šibki int. nastopajo zarotirana stanja spodnjih kvarkov:

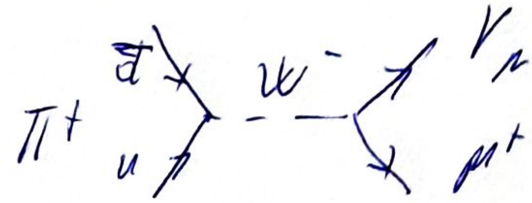
$$\begin{bmatrix} d' \\ s' \end{bmatrix} = \begin{bmatrix} \cos\theta_c & \sin\theta_c \\ -\sin\theta_c & \cos\theta_c \end{bmatrix} \begin{bmatrix} d \\ s \end{bmatrix}$$

Pri sklapljanju (interakciji) zgornjih in spodnjih kvarkov (preko $W^\pm$ oz. nabite šibke int.) dobimo

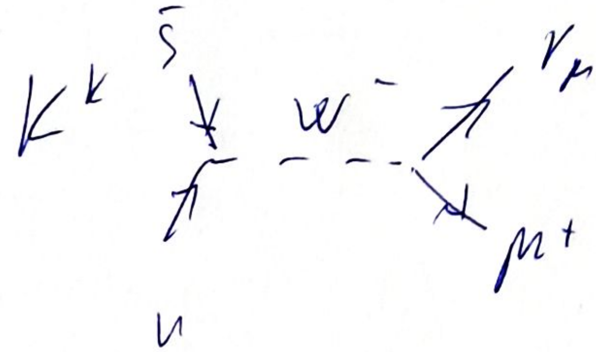
$$[\bar{u}, \bar{c}] \begin{bmatrix} d' \\ s' \end{bmatrix} = \bar{u} d \cos\theta_c + \bar{u} s \sin\theta_c -$$

$$- \bar{c} d \sin\theta_c + \bar{c} s \cos\theta_c$$

⇒ torej



$|M|^2 \propto \cos^2\theta_c$



$|M|^2 \propto \sin^2\theta_c$

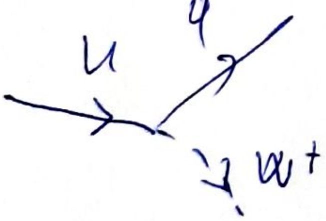
Na podlagi meritev pogostosti zgornjih procesov: $\theta_C \simeq 13^\circ$.

Kobayashi in Maskawa sta l. 1973 predlagala razširitev na 3 gener. kvarkov (čeprav še nijo bili odkriti). Razlog za to je bila razlaga kršitve CP.

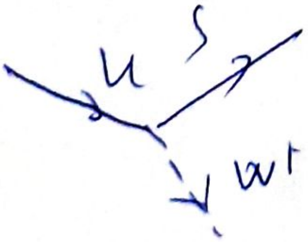
K

$$\begin{bmatrix} d' \\ s' \\ b' \end{bmatrix} = V_{CKM} \begin{bmatrix} d \\ s \\ b \end{bmatrix}$$

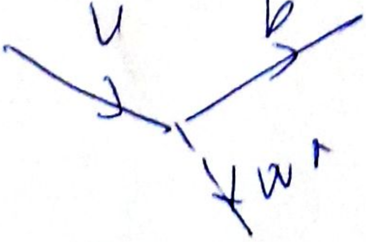
$$V_{CKM} = \begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix}$$



$\mathcal{M} \propto V_{ud}$



$\mathcal{M} \propto V_{us}$



$\mathcal{M} \propto V_{ub}$

13

Elem. V_{CKM} so kompleksni, potrebni jih je določiti iz eksp. ~~Matr~~ Matrika CKM je unitarna, $V_{CKM} V_{CKM}^{+} = I$.

Eksp. slika!

$$\begin{bmatrix} |V_{ud}| & |V_{us}| & |V_{ub}| \\ |V_{cd}| & |V_{cs}| & |V_{cb}| \\ |V_{td}| & |V_{ts}| & |V_{tb}| \end{bmatrix} \approx \begin{bmatrix} 0{,}974 & 0{,}225 & 0{,}003 \\ 0{,}225 & 0{,}973 & 0{,}041 \\ 0{,}001 & 0{,}040 & 0{,}999 \end{bmatrix}$$

$\downarrow$ skoraj enotska!

Uporabna param.:

$$V_{CKM} \approx \begin{bmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{bmatrix} + \mathcal{O}(\lambda^4)$$