7. junij 2019

Fizika jedra in osnovnih delcev

2. KOLOKVIJ

1. Za barion Ω_c^0, ki je osnovno stanje kvarkov ssc s tirno vrtilno količino $\ell = 0$ in spinom $1/2$, zapiši valovno funkcijo $|\Omega_c^0(S_z = +1/2)\rangle$. Izračunaj magnetni moment Ω_c^0, če je $m_s = 400\,\mathrm{MeV}$, masa m_c je zelo velika v primerjavi z m_s, naboja sta $q_s = -e_0/3$, $q_c = 2e_0/3$.

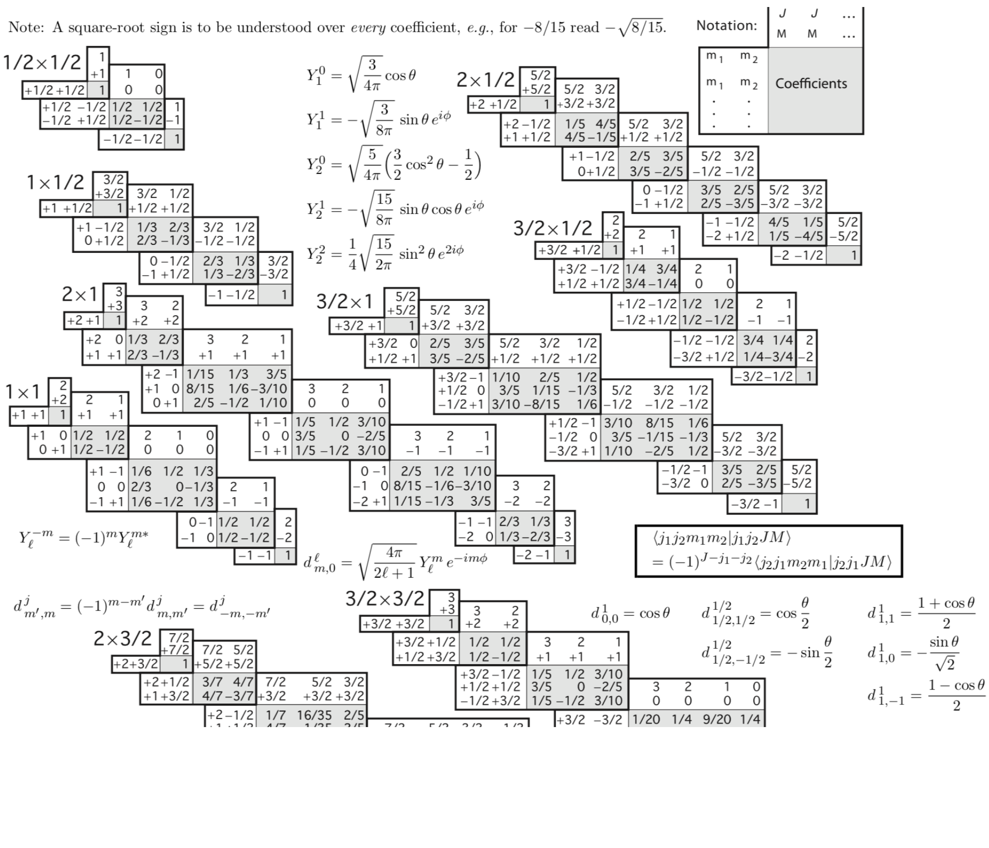
2. Ali naslednji procesi lahko potekajo v okviru Standardnega modela (preko močne, šibke, ali elektromagnetne interakcije)? Če potekajo, skiciraj dominanten Feynmanov diagram, ki prispeva k amplitudi, sicer utemelji, zakaj proces ne poteka.

   - $p\pi^- \to \pi^0 n$
   - $D^+(c\bar{d}) \to \tau^+\nu_\tau$
   - $p\bar{n} \to pn$
   - $n \to \bar{p}e^+\nu_e$
   - $n \to pe^-\bar{\nu}_e$
   - $n \to p\mu^-\bar{\nu}_\mu$
   - $\Sigma^+(uus) \to \pi^+ n$
   - $\tau \to \nu_\tau\mu^+\mu^-$

   Za sipalne procese lahko predpostaviš, da je energija trkov dovolj velika za tvorbo končnega stanja. Pri razpadih upoštevaj sledeče mase: $m_p \approx m_n = 938\,\mathrm{MeV}$, $m_n - m_p \approx 1.2\,\mathrm{MeV}$, $m_\pi = 140\,\mathrm{MeV}$, $m_D = 1860\,\mathrm{MeV}$, $m_\mu = 106\,\mathrm{MeV}$, $m_e = 511\,\mathrm{keV}$, $m_\tau = 1778\,\mathrm{MeV}$, $m_\Sigma = 1189\,\mathrm{MeV}$.

3. V detektorju nevtrinov zaznavamo $\bar{\nu}_e$ preko nabite šibke interakcije s kvarki, kjer v končnem stanju opazimo e^+. Izračunaj spinsko povprečen presek za reakcijo $\bar{\nu}_e u \to e^+ b$. Za težiščno energijo vzemi $\sqrt{s} = 7\,\mathrm{GeV}$ in zanemari mase vseh delcev, $V_{ub} = 0.0039$. Zapiši tudi kotno porazdelitev izhodnega e^+ po kotu ϑ med e^+ in $\bar{\nu}_e$. Preveri, da dobiš enako kotno porazdelitev, če uporabiš rotacijo vhodnega stanja in funkcije $d^j_{m'm}$.

   Dodatna naloga (0.375 točke): Določi kotno porazdelitev za $\bar{\nu}_e u \to e^+ b$, če upoštevaš končno maso $m_b (= 4.2\,\mathrm{GeV})$.



1. $\Omega_c^0 \, (ssc)$

kot proton, $u \to s$, $d \to c$

$$|\Omega_c^0(\uparrow)\rangle = \frac{1}{\sqrt{2}\cdot 3}\Big(|ssc\rangle\big(2|\uparrow\uparrow\downarrow\rangle - |\uparrow\downarrow\uparrow\rangle - |\downarrow\uparrow\uparrow\rangle\big)$$
$$+ |scs\rangle\big(2|\uparrow\downarrow\uparrow\rangle - |\uparrow\uparrow\downarrow\rangle - |\downarrow\uparrow\uparrow\rangle\big)$$
$$+ |css\rangle\big(2|\downarrow\uparrow\uparrow\rangle - |\uparrow\downarrow\uparrow\rangle - |\uparrow\uparrow\downarrow\rangle\big)\Big)$$

$$\mu_p = \frac{4\mu_u - \mu_d}{3} \Rightarrow \mu_\Omega = \frac{4\mu_s - \mu_c}{3}$$

$$\mu_s = \frac{-e_0\hbar}{6m_s}, \quad \mu_c = \frac{e_0\hbar}{3m_c} \approx 0$$

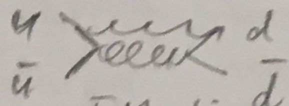
$$\mu_\Omega = \frac{4}{3}\mu_s = \frac{-4e_0\hbar}{3\cdot 6\, m_s} = -\frac{2}{9}\frac{2m_p}{m_s}\underbrace{\frac{e_0\hbar}{2m_p}}_{\mu_N}$$

$$= -\frac{4}{9}\frac{m_p}{m_s}\mu_N = -1{,}0\,\mu_N$$

2. $p\pi^- \to \pi^0 n$

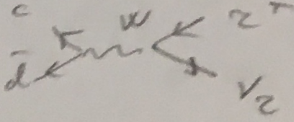
$u \to d$ (proton → neutron)
$\bar{u} \to \bar{d}$ ($\pi^- \to \pi^0$)

u	u		
u	d		
d	d		
$\bar{u}$	$\bar{u}$	ali	d
d	u		$\bar{d}$



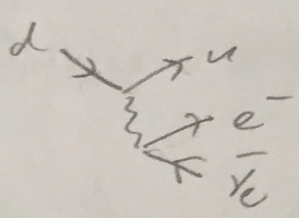
EM ali močna

• $D^+ \to e^+\nu_e \;\equiv\; c\bar{d} \to e^+\nu_e$



• $p\bar{n} \not\to pn$ barionsko število

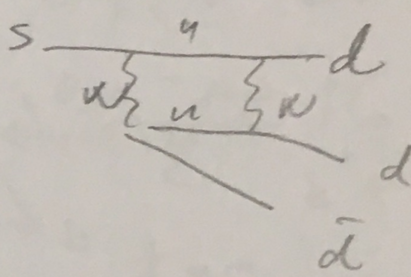
- $n \not\to \bar{p}\, e^+ \nu_e$ barionsko št.!
- $n \to p\, e^- \bar{\nu}_e \;=\; d \to u\, e^- \bar{\nu}_e$



- $n \not\to p\, \mu^- \bar{\nu}_\mu$ premajhna masa n
- $\Sigma^+ (uus) \to \pi^+ n$

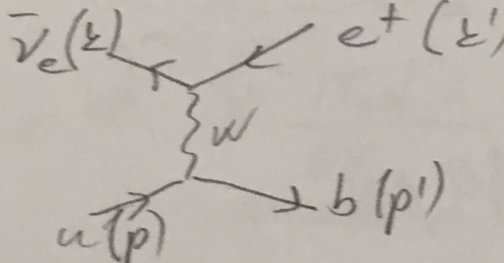
  $uus \to u\bar{d}\; udd$

  $\equiv \; s \to d d \bar{d}$



- $\tau \not\to \nu_\tau \mu^+ \mu^-$ naboj

(3.) $\bar{\nu}_e u \to e^+ b$



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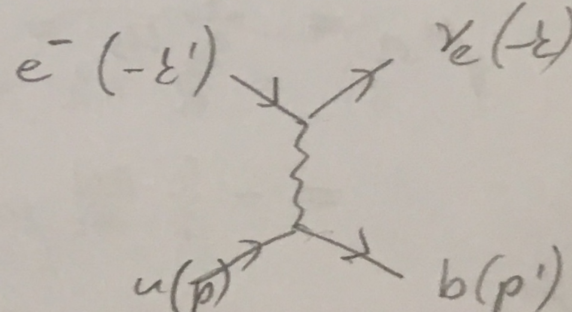
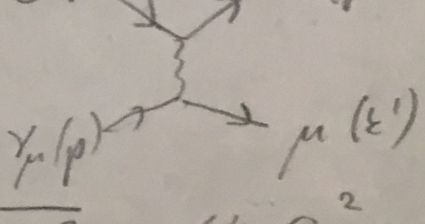


~~zaradi dveh polarizacij kvarka u~~

$$\overline{|M|^2} = \frac{1}{2}\, 64\, G_F^2\, |V_{ub}|^2 \,(-k \cdot p')\,(-k' \cdot p) \;\Leftarrow$$

na vajah pokazali, da je za



$$\overline{|M|^2} = 64\, G_F^2\, p' \cdot k'\; k \cdot p$$

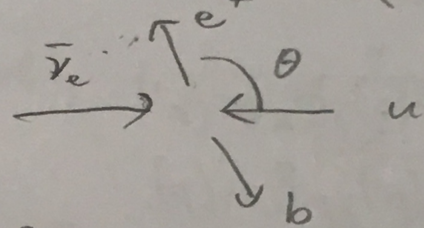
$$\frac{d\sigma}{d\Omega} = \frac{1}{64\pi^2 s}\,\frac{p_f}{p_i}\,\overline{|\mathcal{M}|^2}$$

$$= \frac{1}{64\pi^2 s}\cdot 34\, G_F^2\, |V_{ub}|^2\, k\cdot p'\, k'\cdot p$$

$$u \equiv (k'-p)^2 \Rightarrow k\cdot p' = k'\cdot p = -\frac{u}{2}$$

$$\frac{d\sigma}{d\Omega} = \frac{1}{\cancel{2}\pi^2 s}\, G_F^2\, |V_{ub}|^2\, \frac{u^2}{4}$$

$$u = -2p\cdot k' = -2\,\frac{s}{4}(1+\cos\theta) = -\frac{s}{2}(1+\cos\theta)$$



$$p^\mu = \left(\frac{\sqrt{s}}{2}, 0, 0, -\frac{\sqrt{s}}{2}\right)$$

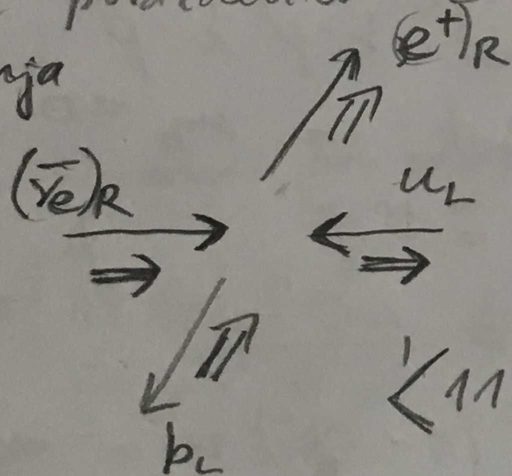
$$k' = \left(\frac{\sqrt{s}}{2}, \frac{\sqrt{s}}{2}\hat{k}\right)$$

$$\frac{d\sigma}{d\Omega} = \frac{2G_F^2|V_{ub}|^2 s}{32\pi^2}(1+\cos\theta)^2$$

$$\sigma = \frac{2G_F^2|V_{ub}|^2 s}{32\pi^2}\underbrace{\int d\Omega\,(1+\cos\theta)^2}_{4\pi + 2\pi\cdot\frac{2}{3} = 4\pi\cdot\frac{4}{3}}$$

$$\sigma = \frac{G_F^2|V_{ub}|^2 s}{3\cancel{8}\pi}$$

kotna porazdelitev z rotacijo vhodnega stanja



vhodno stanje $|1\,1\rangle$

izhodno stanje $|1\,1\rangle'$

$$'\langle 1 1 | 1 1\rangle = '\langle 1 1 | \sum_{m'm} d^1_{m'm}(-\theta)\,|1 m'\rangle$$

$$\Rightarrow |\mathcal{M}|^2 \sim |d^1_{11}|^2 \sim (1+\cos\theta)^2, \quad d^1_{11}(-\theta) = \frac{1+\cos\theta}{2}$$

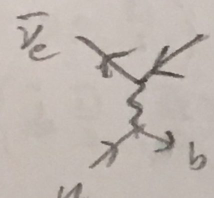
če upoštevamo končno maso m_b:

$$\frac{d\sigma}{d\Omega} = \frac{1}{64\pi^2 s}\,\frac{p_f}{p_i}\,\overline{|\mathcal{M}|^2}$$

$$\frac{p_f}{p_i} = \frac{\frac{\sqrt{s}}{2}\left(1-\frac{m_b^2}{s}\right)}{\sqrt{s}/2} = 1-\frac{m_b^2}{s}$$

$$(\overset{b}{p'}+\overset{e^+}{k'})^2 = s$$
$$= m_b^2 + 2k'\cdot p'$$
$$k'\cdot p' = E_{e^+}(\sqrt{s}-E_{e^+}) + \underbrace{|\vec{p}_{e^+}|}_{p_f = E_{e^+}}\,\underbrace{|\vec{p}_b|}_{p_f}$$
$$m_b^2 + 2\left(p_f(\sqrt{s}-p_f) + p_f^2\right) = s$$
$$m_b^2 + 2\sqrt{s}\,p_f = s$$
$$p_f = \frac{s-m_b^2}{2\sqrt{s}}$$

Za $\overline{|\mathcal{M}|^2}$ dobimo



$$\mathcal{M} \sim \bar{v}(k)\gamma^\mu P_L v(k')\;\bar{u}(p')\gamma_\mu P_L u(p)$$

spremeni se sled toka kvarkov

$$\mathrm{Tr}\left[(\not{p}' + m_b)\gamma_\mu P_L \not{p}\,\gamma_\nu P_L\right]$$

vendar člen z m_b ne prispeva, ker vsebuje Tr[liho št. γ matrik]

$$\Rightarrow \overline{|\mathcal{M}|^2} = 64\, G_F^2 |V_{ub}|^2\, k\cdot p'\, k'\cdot p$$

isto kot za $m_b = 0$

$$u = (k'-p)^2 \Rightarrow k'\cdot p = -\frac{u}{2}$$
$$k\cdot p' = \frac{m_b^2-u}{2}$$

$$\Rightarrow \frac{d\sigma}{d\Omega} = \frac{1}{4\pi^2 s}\, G_F^2 |V_{ub}|^2 \left(1-\frac{m_b^2}{s}\right) u\,(u-m_b^2)$$

in $u = -\frac{s}{2}(1+\cos\theta)$