$$\left[\bar{u}(k)\gamma^{\nu}(1-\gamma^5)u(p)\right]^{\dagger} = \left[u^{\dagger}(k)\gamma^0\gamma^{\nu}(1-\gamma^5)u(p)\right]^{\dagger} = u^{\dagger}(p)(1-\gamma^5)^{\dagger}\gamma^{\nu\dagger}\gamma^{0\dagger}u(k) = u^{\dagger}(p)(1-\gamma^5)\gamma^{\nu\dagger}\gamma^0 u(k) =$$

$$\gamma^{\nu\dagger}\gamma^0 = \gamma^0\gamma^{\nu} \longrightarrow \; = + u^{\dagger}(p)\gamma^0(1+\gamma^5)\gamma^{\nu}u(k) = \bar{u}(p)\gamma^{\nu}(1-\gamma^5)u(k)$$

PODOBNO $\left[\bar{u}(p')\gamma_{\nu}(1-\gamma^5)v(k')\right]^{\dagger} = v(k')\gamma_{\nu}(1-\gamma^5)u(p')$

M.S.

$$\overline{|\mathcal{M}|^2} = \frac{G_F^2}{4}\sum_{\substack{\text{SPINA}\\ \mu,\nu_\mu}}\left[\bar{u}(k)\gamma^{\mu}(1-\gamma^5)u(p)\right]\left[\bar{u}(p)\gamma^{\nu}(1-\gamma^5)u(k)\right]\sum_{\substack{\text{SPINA}\\ e,\nu_e}}\left[\bar{u}(p')\gamma_{\mu}(1-\gamma^5)v(k')\right]\left[\bar{v}(k')\gamma_{\nu}(1-\gamma^5)u(p')\right]$$

$$= \frac{G_F^2}{4}\operatorname{Tr}\left[(\not{k}+m_{\nu_\mu})\gamma^{\mu}(1-\gamma^5)(\not{p}+m_{\mu})\gamma^{\nu}(1-\gamma^5)\right]\operatorname{Tr}\left[(\not{p}'+m_e)\gamma_{\mu}(1-\gamma^5)(\not{k}'-m_{\nu_e})\gamma_{\nu}(1-\gamma^5)\right]$$

UPOŠTEVAMO $m_{\nu_\mu}\simeq 0$, $m_{\nu_e}\simeq 0$, $m_e \ll m_{\mu}$, PRODUKT LIH. ŠTEVILA $\gamma = 0$

$$\overline{|\mathcal{M}|^2} = \frac{G_F^2}{4}\operatorname{Tr}\left[\not{k}\gamma^{\mu}(1-\gamma^5)(\not{p}+m_{\mu})\gamma^{\nu}(1-\gamma^5)\right]\operatorname{Tr}\left[\not{p}'\gamma_{\mu}(1-\gamma^5)\not{k}'\gamma_{\nu}(1-\gamma^5)\right]$$

+ IZREKI O SLEDI

$$\boxed{\overline{|\mathcal{M}|^2} = \frac{G_F^2}{4}\,256\,(k\cdot p')(p\cdot k')}$$

V TEŽIŠČNEM SISTEMU MIONA $\vec{p}=0$; $p=(m_{\mu},0)$

$$(k-p')^2 = \underbrace{k^2}_{m_{\nu_\mu}^2=0} + \underbrace{p'^2}_{m_e^2\to 0} - 2k\cdot p' \Rightarrow (k\cdot p') = -\frac{1}{2}(k-p')^2 \qquad (p-k')^2 = \underbrace{p^2}_{m_\mu^2} + \underbrace{k'^2}_{m_{\nu_e}^2=0} - 2p\cdot k'$$

$$p = p'+k'+k \Rightarrow p-k' = p'+k \Rightarrow (p-k')^2 = (p'+k)^2 = \underbrace{p'^2}_{m_e^2\to 0} + \underbrace{k^2}_{m_{\nu_\mu}^2=0} + 2p'\cdot k$$

$(p-k')^2 = 2p'k \qquad k' = (\omega', \vec{k}') \qquad p = (m_\mu, 0) \qquad (p-k)^2 = (m_\mu - \omega')^2 - \vec{k}'^2$

$(p \cdot k') = m_\mu \omega'$

$$\overline{|\mathcal{M}|^2} = \frac{G_F^2}{4} 256 \cdot \frac{1}{2} \left[m_\mu^2 - 2 m_\mu \omega' + \omega'^2 - \underbrace{\vec{k}'^2}_{=\omega'^2} \right] \cdot m_\mu \omega' =$$

$$= G_F^2 \cdot 32\, m_\mu^2 \left[m_\mu - 2\omega' \right] \omega'$$

$$d\Gamma = \frac{\overline{|\mathcal{M}|^2}}{2E} dQ = \frac{1}{2m_\mu} G_F^2\, 32\, m_\mu^2 (m_\mu - 2\omega')\omega' \frac{1}{(2\pi)^5} \frac{d^3p'}{2E'} \cdot \frac{d^3k'}{2\omega'} \delta((p-p'-k')^2)$$

$$d^3p' = 4\pi \underbrace{E'^2}_{=p'^2} \cdot dE' \qquad d^3k' = 2\pi\, \omega'^2\, d\omega'\, d(\cos\vartheta)$$

ϑ: KOT MED $\vec{p}'$ IN $\vec{k}'$ e IN $\bar{\nu}_e$

$p' = (E', 0, 0, E')$

$k' = \omega'(1, \sin\vartheta\cos\varphi, \sin\vartheta\sin\varphi, \cos\vartheta)$

$$\delta((p-p'-k')^2) \underset{DN}{=} \ldots = \delta(m_\mu^2 - 2m_\mu E' - 2m_\mu\omega' + 2E'\omega'(1-\cos\vartheta))$$

$$= \delta(\ldots\ldots + 2E'\omega'\cos\vartheta) = \frac{1}{2E'\omega'} \delta(\ldots + \cos\vartheta)$$

$$d\Gamma = \frac{G_F^2}{2\pi^3} m_\mu \omega' (m_\mu - 2\omega')\, dE'\, d\omega'\, \delta(\ldots + \cos\vartheta)\, d(\cos\vartheta)$$

$$\frac{m_\mu^2 - 2m_\mu E' - 2m_\mu\omega' + 2E'\omega'}{2E'\omega'} = \cos\vartheta$$

$$\frac{m_\mu^2 - 2m_\mu E' - 2m_\mu\omega'}{2E'\omega'} + 1 = \cos\vartheta$$

$-1 \leq \cos\vartheta \leq 1$

$-2 \leq \frac{m_\mu^2 - 2m_\mu E' - 2m_\mu\omega'}{2E'\omega'} \leq 0$

$m_\mu(m_\mu - 2E' - 2\omega') \leq 0$

$\Rightarrow \omega' \geq \frac{m_\mu}{2} - E'$

$\downarrow$ NASLEDNJA STRAN

DESNI NEENAČAJ : $\boxed{\omega' \geq \frac{m_\mu}{2} - E'}$

LEVI NEENAČAJ : $-4E'\omega' \leq m_\mu^2 - 2m_\mu E' - 2\omega' m_\mu$

$-4\omega'\left(E' - \frac{m_\mu}{2}\right) \leq m_\mu\left(m_\mu - 2E'\right)$

$-2m_\mu\left(E' - \frac{m_\mu}{2}\right)$

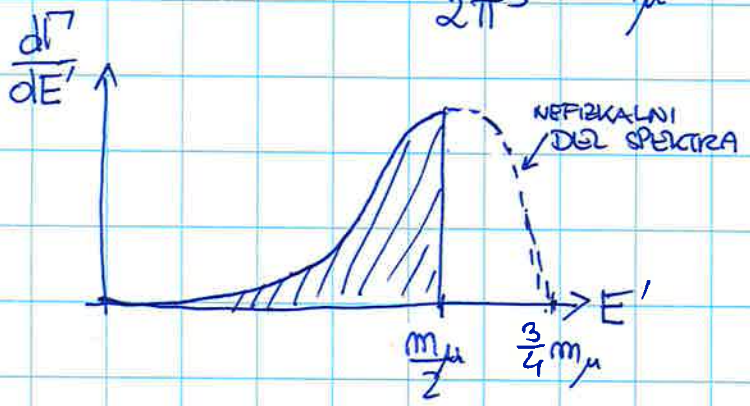
ČE BI μ RAZPADAL V DVA DELCA ($0 \sim m$) $\rightarrow E' = \frac{m_\mu}{2}$; 3 DELCI $\Rightarrow E' < \frac{m_\mu}{2}$

$\Rightarrow \boxed{\omega' \ngtr\, \leq \frac{m_\mu}{2}}$

$\vec{k}'$ $\bar{\nu}_e \leftarrow \mu \rightarrow e,\ \nu_\mu$

$\nu_\mu \leftarrow \quad \rightarrow E'\, e,\ \bar{\nu}_e$

$$d\Gamma = \frac{G_F^2}{2\pi^3} m_\mu\, dE' \int_{\frac{m_\mu}{2} - E'}^{\frac{m_\mu}{2}} d\omega'\, \omega' \left(m_\mu - 2\omega'\right) \Rightarrow \frac{d\Gamma}{dE'} = \frac{G_F^2}{12\pi^3} \cdot m_\mu^2 E'^2 \left(3 - \frac{4E'}{m}\right)$$



$$\Gamma = \int \frac{d\Gamma}{dE'}\, dE' = \frac{G_F^2}{12\pi^3} \int_0^{\frac{1}{2}m_\mu} m_\mu^2 E'^2 \left(3 - \frac{4E'}{m}\right) dE' =$$

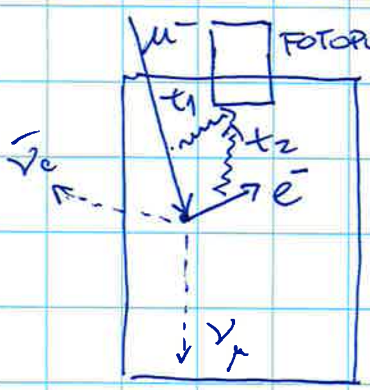
$$\boxed{\Gamma = \frac{G_F^2}{192\pi^3} \cdot m_\mu^5}$$

$$\tau_\mu = \frac{\hbar}{\Gamma} = 2{,}1\,\mu s$$

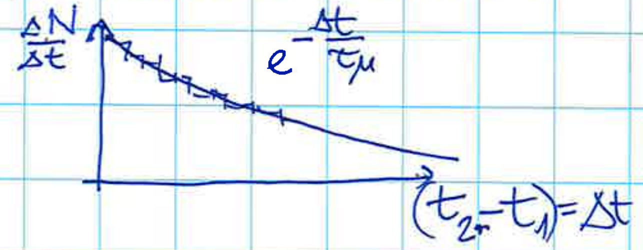
RAZPAD MIONA - POSKUS

MUONI NASTAJAJO V ATMOSFERI $\quad p + A \rightarrow p \ldots + \pi + \pi + \ldots$

$\pi^- \rightarrow \mu^- \bar{\nu}_\mu \qquad \pi^+ \rightarrow \mu^+ \nu_\mu$



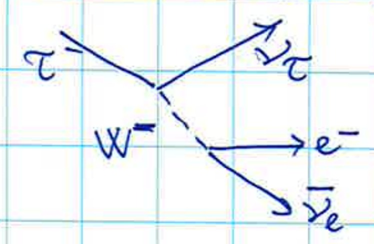
OLJE-SCINTILATOR - ZASVETI, ČE NABIT DELEC VZBUDI MOLEKULE

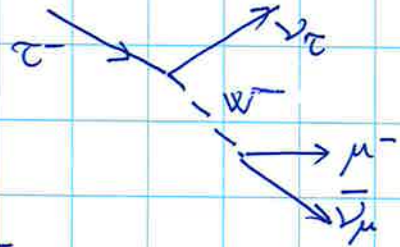


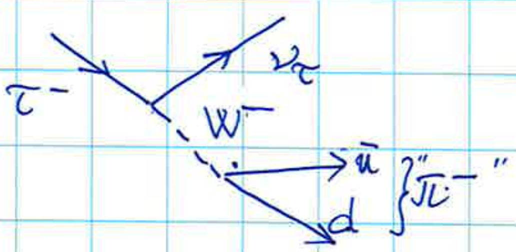
IZMERIMO $\tau_\mu \longrightarrow$ DOLOČIMO G_F

RAZPADNA ŠIRINA ZA LEPTON τ^- $\qquad m_\tau \sim 1.8\ \mathrm{GeV}$

$\tau^- \to e^- \bar{\nu}_e \nu_\tau \qquad \tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau \qquad \tau^-$





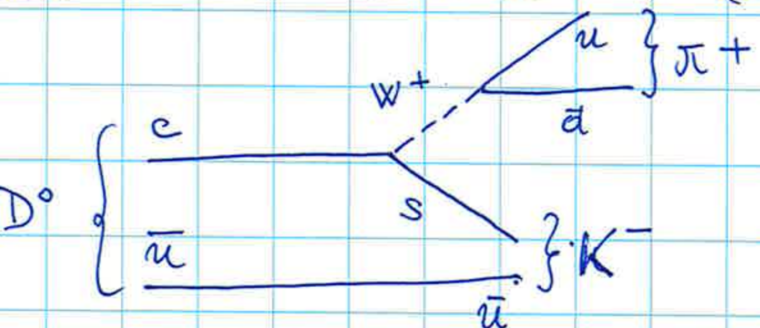


$$\Gamma(\tau^- \to e^- \bar{\nu}_e \nu_\tau) = \frac{G_F^2}{192} \frac{m_\tau^5}{\pi^3} \qquad \Gamma(\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau) \doteq \frac{G_F^2}{192\pi^3} m_\tau^5 \qquad \Gamma(\tau^- \to \pi^- \nu_\tau) \doteq 3\, \frac{G_F^2 m_\tau^5}{192\pi^3}$$

$$\Gamma = \frac{\hbar}{\tau_\tau} = \Gamma(\tau^- \to e^- \bar{\nu}_e \nu_\tau) + \Gamma(\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau) + \Gamma(\tau^- \to \text{"}\pi^-\text{"} \nu_\tau) = 5\, \frac{G_F^2}{192} \frac{m_\tau^5}{\pi^3}$$

$$\frac{\tau_\tau}{\tau_\mu} = \frac{1}{5} \cdot \left(\frac{m_\mu}{m_\tau}\right)^5 \qquad \text{DN: } \tau_\tau = ?$$

ŠIBKI RAZPADI MEZONOV $\qquad D^0 \to K^- \pi^+ \qquad (c\bar{u}) \to (s\bar{u}) + (u\bar{d})$



$\bar{u}$: SPEKTATOR

NAIVNO:

$\Gamma(D^0 \to K^- \pi^+) \propto m_D^5$

KER PA $m_D = 1.865\ \mathrm{GeV}$, $m_K \sim 0.5\ \mathrm{GeV}$, $m_\pi = 0.135\ \mathrm{GeV} \Rightarrow$ BOLJŠE $\Gamma(D \to K\pi) \propto (m_D - m_K)^5$

KAJ PA RAZPAD $\quad D^0 \to K^- K^+$?