Sipanje protonov na kozmičnem mikrovalovnem ozadju

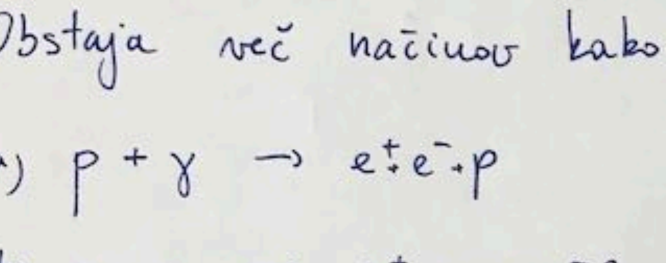
COSMIC MICROWAVE BACKGROUND = CMB

$T_\gamma = 2{,}74\,K \quad E_\gamma = kT_\gamma = 2{,}3\cdot 10^{-4}\,eV \quad (k \sim 10^{-4}\,eV/K)$

Obstaja več načinov kako p izgubi energijo, $E \gg M_p c^2$, $\sim pc$

a) $p + \gamma \to e^+ e^- p$ tvorba parov e^+e^-

b) $p + \gamma \to \Delta^+ \to p + \pi^0$ Δ^+ resonanca



$$((E, pc) + (E_\gamma, -E_\gamma))^2 = (M + 2m_e)^2 c^4$$

$$(E+E_\gamma)^2 - (pc - E_\gamma)^2 = \underbrace{E^2-(pc)^2}_{M^2c^4} + 2EE_\gamma + E_\gamma^2 + 2pcE_\gamma - E_\gamma^2 = (M^2 + 4mM + 4m^2)c^4$$

$$\Rightarrow 4EE_\gamma = 4m_e M_p c^4 \qquad E_{a)} = \frac{m_e M_p c^4}{E_\gamma} = \frac{5\cdot 10^5\,eV \cdot 10^9\,eV}{2\cdot 10^{-4}\,eV}$$

$$\sim 2{,}5\cdot 10^{18}\,eV \cong 10^9\,GeV$$

b) $2m_e \to m_\pi$

$$4EE_\gamma = 4m_\pi(2M_p + m_\pi)c^4 \qquad E_{b)} = \frac{m_\pi c^2(2M_p c^2 + m_\pi c^2)}{4E_\gamma}$$

$$= \frac{0{,}1\,GeV \cdot 2\,GeV}{4\cdot 2\cdot 10^{-4}\,eV} = \frac{1}{4}\cdot 10^{+21}\,eV$$

$$= 2{,}5\cdot 10^{20}\,eV$$

$\sigma \sim 0.1\,mb$

$\rho \sim 400/cm^3$

$$\lambda \sim \frac{1}{\rho\sigma} = 5\,Mpc$$

(6) $B = 0{,}002\,T$ $pc = eBrc$

$\Theta = 90°$ $= 2\cdot 10^{-3}\,\frac{eVs}{m^2}\cdot 2\cdot 10^{-2}\,m\cdot 3\cdot 10^{8}\,\frac{m}{s}$

$r = 2\,cm$ $= 12\cdot 10^{3}\,eV = 12\,keV < m_e c^2$

$$T_e \sim \frac{(pc)^2}{2m_e c^2} = \frac{12^2\,keV^2}{10^3\,keV} = 0{,}14\,keV$$

Compton: $\lambda' - \lambda = \lambda_c(1-\cos(\Theta)) = \lambda_c$ ($\Theta = 90°$, $\cos = 0$)

Energija: $E_\gamma + mc^2 = E_\gamma' + mc^2 + T_e$, $E_\gamma = \frac{hc}{\lambda}$, $E_\gamma' = \frac{hc}{\lambda'}$

$$hc\left(\frac{1}{\lambda} - \frac{1}{\lambda'}\right) = T_e \quad /\lambda\lambda'$$

$$hc(\lambda' - \lambda) = hc\lambda_c = \lambda\lambda' T_e = \lambda(\lambda+\lambda_c)T_e$$

$$= \frac{hc}{mc^2}$$

Kvadratna enačba za λ

$$\lambda^2 + \lambda_c\lambda - \frac{(hc)\lambda_c}{T} = 0$$

$$\lambda = \frac{1}{2}\left(-\lambda_c + \sqrt{\lambda_c^2 + \frac{4(hc)\lambda_c}{T}}\right)$$

$\lambda_c = \frac{hc}{mc^2} = \frac{2\cdot 1240\,eV\,nm}{2\cdot 500\cdot 10^3\,eV} = 2{,}4\cdot 10^{-3}\,nm = 2{,}4\,pm$

$$= \frac{\lambda_c}{2}\left(-1 + \sqrt{1 + 4\frac{hc}{T\lambda_c}}\right), \quad \frac{hc}{T\lambda_c} = \frac{m_e c^2}{T_e} \gg 1$$

$$\simeq \underbrace{\frac{hc}{mc^2}}_{\lambda_c}\sqrt{\frac{hc}{\lambda_c T}} = ~~2{,}4\cdot 10^{-3}\,nm \cdot \sqrt{} = \sqrt{2}\,2{,}4\cdot 10^{-3}\,nm \cdot \sqrt{}~~$$

$$= 2{,}4\cdot 10^{-3}\,nm \cdot \sqrt{\frac{mc^2}{T}} \sim \underline{0{,}1\,nm}$$

$$\sqrt{\frac{2(mc)^2}{(pc)^2}} = \sqrt{2}\cdot\frac{511\,keV}{12\,keV} \sim 50$$

(7) Sevanje Čerenkova : $v > c_v = \frac{c}{n} \Rightarrow \beta > \frac{3}{4}$

$E_\gamma = \text{MeV}$

$n \sim \frac{4}{3}$

$\theta = ?$

$\varphi = ?$

$$\gamma = \frac{1}{\sqrt{1-\frac{9}{16}}} = \frac{4}{\sqrt{7}}$$

$$T = (\gamma - 1) m_e c^2 = \left(\frac{4}{\sqrt{7}} - 1\right) 511\,\text{keV}$$

$$\cong \frac{1}{4}\,\text{MeV}$$

energija: $E_\gamma + \cancel{mc^2} = E_\gamma' + T + \cancel{mc^2}$

$$E_\gamma' = E_\gamma - T = \left(1 - \frac{1}{4}\right)\text{MeV} = 0.75\,\text{MeV}$$

$$\lambda' - \lambda = \lambda_c \,(1 - \cos\theta)$$

$$m_e c^2 \left(\frac{1}{E_\gamma'} - \frac{1}{E_\gamma}\right) = 0{,}5\,\cancel{\text{MeV}}\left(\frac{4}{3} - 1\right)\frac{1}{\cancel{\text{MeV}}} = \frac{1}{6} = 1 - \cos\theta$$

$$\cos\theta = 1 - \frac{1}{6} \sim 1 - \frac{\theta^2}{2} \Rightarrow \theta \sim \frac{1}{\sqrt{3}} \cdot \frac{180^\circ}{\pi} \sim 36^\circ$$

(8) $\lambda_{DB} = \lambda_c$ → iz mirovne mase elektrona $\quad \lambda_c = \frac{hc}{mc^2}$

↑ iz gibalne količine e^- : $\lambda_{DB} = \frac{h}{p} = \frac{hc}{pc}$

$\Rightarrow pc = mc^2 \Rightarrow \gamma\beta = 1 \rightarrow \beta^2 = 1 - \beta^2 \Rightarrow \beta = \frac{1}{\sqrt{2}}$.

(9) $\lambda = 0{,}071\ nm$ Zavorno sevanje

$\theta = 45^\circ$

$p_e = ?$

$U_{min} = ?$

$$eU = E_\gamma = \frac{hc}{\lambda} = \frac{1240\ eV\,nm}{0{,}07\ nm}$$

$$= 17{,}4\ keV \quad , U_{min} = 17{,}4\ V$$

$$\lambda' - \lambda = \lambda_c (1 - \cos\theta)$$

$$\frac{1}{E_\gamma'} = \frac{1}{E_\gamma} + \frac{1 - \sqrt{2}/2}{m_e c^2}$$

$$E_\gamma' = \frac{E_\gamma m_e c^2}{mc^2 + E_\gamma (1 - \sqrt{2}/2)}$$

$$= \frac{E_\gamma}{1 + \frac{E_\gamma (1 - \sqrt{2}/2)}{m_e c^2}} \sim E_\gamma$$

$$\frac{17\ keV \cdot 0{,}3}{511\ keV} \sim 10^{-2}$$

p_e: $E_\gamma - E_\gamma' \cos\theta = cp \cos\varphi \ /^2$

$E_\gamma' \sin\theta = cp \sin\varphi \ /^2$) +

$$E_\gamma^2 + E_\gamma'^2 - 2E_\gamma E_\gamma' \cos\theta = (cp)^2$$

$$\sqrt{2E_\gamma^2 (1 - \cos\theta)} = cp = 17{,}4\ keV \sqrt{2\left(1 - \frac{\sqrt{2}}{2}\right)} = \underline{13{,}3\ keV}$$

$$2 - \sqrt{2} = 0{,}6 \sim 0{,}8$$