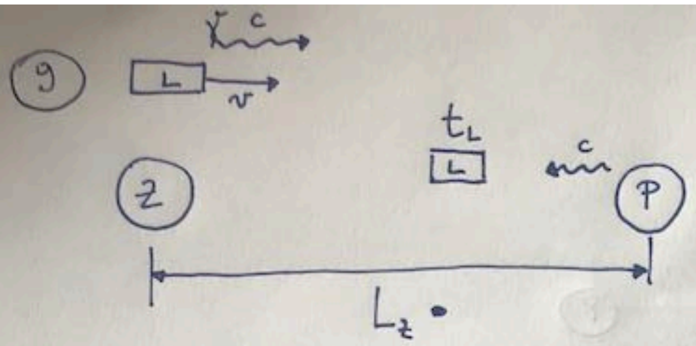
9



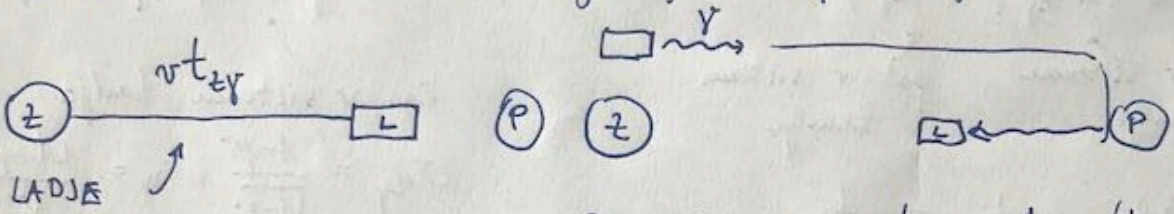

$L_z = 4\, c\, td$

$t_{L\gamma} = 6\ td$

$v = ?$

$t_{LP} = ?$

i) ~~DIREKTNO~~ v sistemu Zemlje je čas potovanja $t_{z\gamma}$




POT LADJE

POT SIGNALA : $c t_{z\gamma} = L_z + (L_z - v t_{z\gamma})$

URE NA LADJI SO POČASNEJŠE

$$\Rightarrow c(1+\beta)\, t_{z\gamma} = 2L_z$$

$$t_{z\gamma} = \frac{2L_z}{c(1+\beta)}$$

$$t_L = \frac{t_z}{\gamma}$$

$$t_{L\gamma} = \frac{2L_z}{c}\,\frac{\sqrt{1-\beta^2}}{1+\beta} = \frac{2L_z}{c}\sqrt{\frac{1-\beta}{1+\beta}}$$

OD TOD DOBIMO HITROST

$$\left(\frac{\cancel{6}\,\cancel{c td}\; 3}{\cancel{8}\,\cancel{c td}\; 4}\right)^2 = \left(\frac{c\, t_{L\gamma}}{2L_z}\right)^2 = \frac{1-\beta}{1+\beta}$$

$$\beta\left(\frac{c\, t_{L\gamma}}{2L_z}\right)^2 + 1 = 1 - \left(\frac{c\, t_{L\gamma}}{2L_z}\right)^2$$

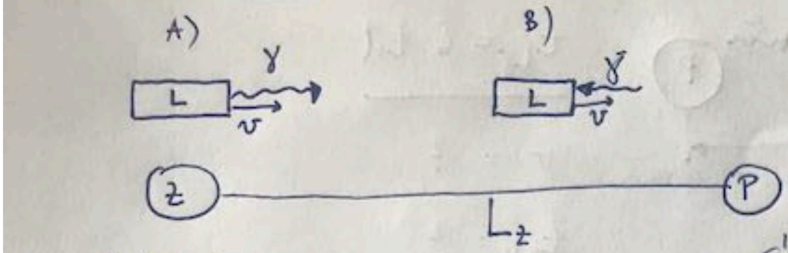
$$\beta = \frac{1-\frac{9}{16}}{1+\frac{9}{16}} = \frac{7}{25} = \frac{28}{100} = \underline{0{,}28}$$

ČAS POTOVANJA LADJE DO POSTAJE, MERJENO NA ZEMLJI

$$t_{zP} = \frac{L_z}{v} = \frac{28\,\cancel{c}\,\text{dni}}{0{,}28\,\cancel{c}} = 100\ \text{dni}, \quad t_{LP} = \frac{t_{zP}}{\gamma} \doteq 100\ \text{dni}\,\sqrt{1-0{,}3^2} = 96\ \text{dni}$$

$$\sim 1 - \tfrac{1}{2}0{,}09 \doteq 0{,}96$$

## Z DOGODKI




S: $A(0,0)$

$B(ct_{z\gamma},\ v t_{z\gamma})$

čas v sistemu zemlje — pot v sistemu zemlje

$$\xrightarrow{\text{L.T.}}$$

S': $A'(0,0)$

$B'(\gamma(ct_{z\gamma} - \beta v t_{z\gamma}),\ L_L)$

čas v sistemu ladje

$$ct_{L\gamma} = \frac{1-\beta^2}{\sqrt{1-\beta^2}}\, ct_{z\gamma} = \frac{ct_{z\gamma}}{\gamma}$$

$$2L_z - v t_{z\gamma} = c t_{z\gamma}$$

$$t_{L\gamma} = \frac{2L_z}{c}\sqrt{\frac{1-\beta}{1+\beta}} \quad \Big|^2$$

$$\beta = \frac{1-\left(\frac{ct_{L\gamma}}{2L_z}\right)^2}{1+\left(\frac{ct_{L\gamma}}{2L_z}\right)^2} = \frac{28}{100} = 0{,}28$$

$$t_{zP} = \frac{L_z}{\beta c} = \frac{4\,ctd}{0{,}28\,c} = 100 \text{ dni}$$

$$t_{LP} = \frac{t_{zP}}{\gamma} = \sqrt{1-\beta^2}\, t_{zP} \sim \left(1 - \tfrac{1}{2}(0{,}28)^2\right) 100 \text{ dni} \sim \underline{96 \text{ dni}}$$

(17) Kinetična energija

KLASIČNO : $W_k = \frac{1}{2} m v^2$ , $\vec{p}_k = m\vec{v}$

RELATIVISTIČNO : $cp^\mu = (E, c\vec{p}) = (\gamma mc^2, \gamma \vec{\beta} mc^2)$

POLNA ENERGIJA

$$(cp^\mu)(cp_\mu) = (\gamma^2 - \gamma^2\beta^2)(mc^2)$$

$$= mc^2 \text{ ... INVARIANTA}$$

$$cp^\mu \xrightarrow{\beta=0} (\gamma mc^2, 0) = (mc^2, 0)$$

MIROVNA ENERGIJA

KINETIČNA E. = POLNA E. − MIROVNA. E

$$T = E - mc^2$$

$$= (\gamma - 1) mc^2 \overset{\beta \ll 1}{\simeq} (\cancel{1} + \tfrac{1}{2}\beta^2 - \cancel{1}) mc^2 = \frac{1}{2} m v^2$$

$$\frac{T}{W_k} = R = (1{,}01 \ , 1{,}1 \ , 5)$$

$$\frac{\gamma - 1}{\frac{1}{2}\beta^2} = R \Rightarrow \gamma = \frac{1}{\sqrt{1-\beta^2}} = \frac{R}{2}\underbrace{\beta^2}_{x} + 1 \ /^2$$

$$\left(\left(\frac{R}{2}\right)^2 x^2 + Rx + 1\right)(1-x) = 1$$

$$\left(\frac{R}{2}\right)^2 x^2 + Rx + \cancel{1} - \left(\frac{R}{2}\right)^2 x^3 - Rx^2 - x = \cancel{1} \quad /:x$$

$$-\left(\frac{R}{2}\right)^2 x^2 + \left(\left(\frac{R}{2}\right)^2 - R\right) x + R - 1 = 0$$

$$\frac{R^2}{4} x^2 + \left(\frac{R}{4} - 1\right) R x + 1 - R = 0$$ kvadratna enačba →

$$\frac{R^2}{4}x^2 + R\left(1-\frac{R}{4}\right)x + 1 - R = 0$$

$$x = \frac{-R\left(1-\frac{R}{4}\right) \pm \sqrt{R^2\left(1-\frac{R}{4}\right)^2 - R^2(1-R)}}{4\,\frac{R^2}{2}} \quad \Big/ \cdot 4$$

$$= \frac{\cancel{R}(R-4) \pm \cancel{R}\sqrt{\underbrace{16\left(\cancel{1} - \frac{R}{2} + \frac{R^2}{16} - \cancel{1}(\cancel{1}-R)\right)}_{R^2+8R}}}{\frac{2R^{\cancel{2}}}{\cancel{2}}}$$

$$= \frac{R-4 \pm \sqrt{R(R+8)}}{2R} = \beta^2$$

$$\beta = \sqrt{\frac{R-4 + \sqrt{R(R+8)}}{2R}} = (0{,}115,\ 0{,}35,\ 0{,}95)$$

Limiti : $R = \frac{\gamma - 1}{\frac{1}{2}\beta^2} \simeq \begin{cases} 1, & \beta \sim 0 \\ \gg 1, & \beta \sim 1 \end{cases}$

$$\beta(R \sim 1) = \sqrt{\frac{-3+\sqrt{9}}{2}} \to 0$$

$$\beta(R \gg 1) = \sqrt{\frac{R \cancel{-4} + \sqrt{R^2 \cancel{+8R}}}{2R}} \sim \sqrt{\frac{R+R}{2R}} \to 1.$$

(18) Kinetična energija protona z gibalno količino p

$m_p c^2 = 940$ MeV  Če $pc \ll m_p c^2$ : $T \sim W_k \sim \frac{(pc)^2}{2mc^2}$

$pc = 800$ MeV  Tukaj je $pc \sim m_p c^2$

$E = T + mc^2$ , $E^2 - (pc)^2 = m^2c^4$

$$T + mc^2 = \sqrt{(pc)^2 + m^2c^4}$$

$$T = mc^2\left(\sqrt{1 + \left(\frac{pc}{mc^2}\right)^2} - 1\right)$$

$$\cong \text{GeV}\left(\sqrt{1+\left(\frac{0.8}{1}\right)^2} - 1\right) \simeq 300 \text{ MeV}$$

$\sqrt{1.64} \sim 1.3$  (294