Recimo, da opazovalec v S' takoj, ko pasi, da B pade zadet ($t_2'<0$), ustrelimo pištolo A (ob času $t_3'< 0 = t_1'$, še preden A sproži proti B).

B je še vedno mrtev, vendar brez vzroka (huda težava s kavzalnostjo!)

---

⑤ O tem, da absolutna razdalja ne obstaja

Raketo, ki miruje v S, orientiramo vzdolž $\hat{e}_x$.

$x_1 = 0$ ob (vsakem*) času t_1

$x_2 = l$ ob (vsakem*) času t_2 ; l = dolžina rakete (razdalja med začetkom T_1 in koncem T_2 rakete)

* ker raketa v S miruje.

$$\boxed{D = |\vec{r}_1(t_1) - \vec{r}_2(t_1 = t_2)| = |x_1(t_1) - x_2(t_2 = t_1)| = l}$$

Podobno v sistemu S', ki se s hitrostjo $\vec{v}_0 = v_0\hat{e}_x$ giblje glede na S:

$$\boxed{D' = |\vec{r}_1{}'(t_1') - \vec{r}_2{}'(t_2' = t_1')|}$$

LT:

$$c_0t_1' = \gamma_0 c_0 t_1 \qquad c_0t_2' = \gamma_0(c_0t_2 - \beta_0 l)$$

$$x_1' = -\gamma_0 v_0 t_1 \qquad x_2' = \gamma_0(l - v_0 t_2)$$

$$y_1' = 0 \qquad y_2' = 0$$

$$z_1' = 0 \qquad z_2' = 0$$

$$\Rightarrow D' = |x_1(t_1') - x_2(t_2' = t_1')|$$

$$t_2' = t_1'$$

$$\Rightarrow c_0 t_2' = c_0 t_1' \Rightarrow \gamma_0 c_0 t_1 = \gamma_0 c_0 t_2 - \gamma_0 \beta_0 l$$

$$\Rightarrow c_0 t_1 = c_0 t_2 - \beta_0 l$$

$$\Rightarrow t_2 = t_1 + \frac{\beta_0}{c_0} l$$

$$x_1(t_1') = -\gamma_0 v_0 t_1$$

$$x_2'(t_2' = t_1') = \gamma_0 (l - v_0 t_2) = \gamma_0 \left(l - v_0 t_1 - \frac{v_0}{c_0}\beta_0 l\right) = \gamma_0 (l - v_0 t_1 - \beta_0^2 l)$$

$\hookrightarrow t_2 = t_1 + \frac{\beta_0}{c_0} l$

$$= -\gamma_0 v_0 t_1 + l\gamma_0 \underbrace{(1-\beta_0^2)}_{1/\gamma_0^2} = x_1' + l/\gamma_0$$

$$\Rightarrow \boxed{D' = l/\gamma_0} \overset{\gamma_0 \geq 1}{\leq} l$$ krčenje (kontrakcija) dolžin

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⑥ Skalarji v PTR

Def: skalar ≡ fizikalna količina, invariantna na Lorentzovo transformacijo

- zgornji primer: navadna razdalja ni skalar v PTR

Spomnimo se: skalar v klasični mehaniki ≡ količina, invariantna na rotacijo in translacijo (vzporedni premik)

$\vec{r}$: krajevni vektor točke T

$r = \sqrt{\langle \vec{r}, \vec{r} \rangle}$: razdalja T od izhodišča koordinatnega sistema

$\Rightarrow r^2 = \langle \vec{r}, \vec{r} \rangle$; skalarni produkt $\vec{r}$ s samim sabo

O : operator rotacije ; $O^{-1} = O^{T}$ (unitarna transformacija)

$$\vec{r}\,' = O\vec{r} \Rightarrow r'^2 = \langle \vec{r}\,', \vec{r}\,' \rangle$$
$$= \langle O\vec{r}, O\vec{r} \rangle$$
$$= \langle \vec{r}, O^T O \vec{r} \rangle$$
$$= \langle \vec{r}, \vec{r} \rangle$$
$$= r^2 \quad \text{skalar}$$

$\Rightarrow r' = r$ (v klasični mehaniki je razdalja skalar)

$$r^2 = \langle \vec{r}, \vec{r} \rangle = \langle \mathbb{1}_{3\times3} \vec{r}, \vec{r} \rangle \quad ; \quad \mathbb{1}_{3\times3} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$; Evklidski prostor

---

$$L = \begin{bmatrix} \gamma_0 & -\beta_0\gamma_0 & 0 & 0 \\ -\beta_0\gamma_0 & \gamma_0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}, \quad L^{-1} = \begin{bmatrix} \gamma_0 & \beta_0\gamma_0 & 0 & 0 \\ \beta_0\gamma_0 & \gamma_0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$L_{2,2}$ (podmatrika

$L^T = L \neq L^{-1}$: L ni unitarna (ortogonalna)

$$x'^{\mu} = L x^{\mu}$$

$$\Rightarrow x'^2 = \langle \mathbb{1}_{4\times4} x'^{\mu}, x'^{\mu} \rangle$$
$$= \langle x'^{\mu}, x'^{\mu} \rangle$$
$$= \langle L x^{\mu}, L x^{\mu} \rangle$$
$$= \langle x^{\mu}, L^T L x^{\mu} \rangle$$
$$= \langle x^{\mu}, L^2 x^{\mu} \rangle$$

$L^2 \neq \mathbb{1}_{4\times4}$

$\Rightarrow$ V splošnem $\boxed{\langle \mathbb{1}_{4\times4} X'^{\mu}, X'^{\mu} \rangle \neq \langle \mathbb{1}_{4\times4} X^{\mu}, X^{\mu} \rangle}$

$$\mathbb{1}_{4\times4} \rightarrow G = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & -1 \end{bmatrix}$$

(Psevdo-evklidski prostor, še vedno raven; metrika Minkowskega)

$$G \Rightarrow G X^{\mu} = \begin{bmatrix} c_0 t \\ -x \\ -y \\ -z \end{bmatrix}$$

$$\Rightarrow \langle G X^{\mu}, X^{\mu} \rangle = (X^{\mu})^T G X^{\mu}$$

$$= \begin{bmatrix} c_0 t, x, y, z \end{bmatrix} \begin{bmatrix} c_0 t \\ -x \\ -y \\ -z \end{bmatrix}$$

$$= (c_0 t)^2 - x^2 - y^2 - z^2$$

Velja:
$$LGL = \begin{bmatrix} \gamma_0 & -\beta_0\gamma_0 & 0 & 0 \\ -\beta_0\gamma_0 & \gamma_0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & -1 \end{bmatrix} \begin{bmatrix} \gamma_0 & -\beta_0\gamma_0 & 0 & 0 \\ -\beta_0\gamma_0 & \gamma_0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} \gamma_0 & \beta_0\gamma_0 & 0 & 0 \\ -\beta_0\gamma_0 & -\gamma_0 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & -1 \end{bmatrix} \begin{bmatrix} \gamma_0 & -\beta_0\gamma_0 & 0 & 0 \\ -\beta_0\gamma_0 & \gamma_0 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} \gamma_0^2(1-\beta_0^2) & 0 & 0 & 0 \\ 0 & -\gamma_0^2(1-\beta_0^2) & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & -1 \end{bmatrix}$$

$$= \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & -1 \end{bmatrix}$$

$$= G$$

$$\Rightarrow \boxed{\langle G x'^{\mu}, x'^{\mu} \rangle} = \langle G L x^{\mu}, L x^{\mu} \rangle$$

$$= \langle L^T G L x^{\mu}, x^{\mu} \rangle$$

$$= \langle L G L x^{\mu}, x^{\mu} \rangle \qquad (L^T = L)$$

$$= \boxed{\langle G x^{\mu}, x^{\mu} \rangle} \qquad (L^T = L)$$

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7 Četverec hitrosti

- $\vec{r} \rightarrow x^{\mu}$; $\langle G x'^{\mu}, x'^{\mu} \rangle = \langle G x^{\mu}, x^{\mu} \rangle$

Podobno bi radi:

- $\vec{v} \rightarrow u^{\mu}$; $\langle G u'^{\mu}, u'^{\mu} \rangle = \langle G u^{\mu}, u^{\mu} \rangle$

$$\vec{v} \equiv \frac{d\vec{r}}{dt} \overset{?}{\Longrightarrow} u^{\mu} = \frac{dx^{\mu}}{dt} = \frac{d}{dt}\begin{bmatrix} c_0 t \\ x \\ y \\ z \end{bmatrix} = \begin{bmatrix} c_0 \\ v_x \\ v_y \\ v_z \end{bmatrix}$$

$$\Rightarrow \langle G u^{\mu}, u^{\mu} \rangle = c_0^2 - v^2 = c_0^2/\gamma^2 \; ; \; \boxed{\gamma = \frac{1}{\sqrt{1-\beta^2}} \, , \, \beta^2 = \frac{v^2}{c^2}} \, *$$

Ker v splošnem $v' \neq v$, $\gamma' \neq \gamma$ in

$$\langle G u'^{\mu}, u'^{\mu} \rangle = c_0^2/\gamma'^2 \neq c_0^2/\gamma^2 = \langle G u^{\mu}, u^{\mu} \rangle$$

---

* Pozor! $\gamma \neq \gamma_0 = \frac{1}{\sqrt{1-\beta_0^2}}$, ker $\beta \neq \beta_0 = \frac{v_0}{c_0}$

$$\Rightarrow \boxed{u^\mu \equiv \frac{dx^\mu}{d\tau} \;;\; d\tau = \frac{dt}{\gamma}}$$

$$\Rightarrow \boxed{u^\mu = \begin{bmatrix} \gamma c_0 \\ \gamma \vec{v} \end{bmatrix}} \quad \text{in} \quad \langle G u^\mu, u^\mu \rangle = c_0^2 = \text{Lor. invarianta}$$

* LT u^μ: naslednjih dveh (vstavljenih) listih

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(8) Dopplerjev pojav

• Longitudinalni Dopplerjev pojav

S: mirovni sistem oddajnika

1. blisk: $t_1 = t$, $x_1 = 0$

2. blisk: $t_2 = t + t_0$, $x_2 = 0$

S': mirovni sistem sprejemnika, ki se giblje s hitrostjo v_0 vzdolž $\hat{e}_x = \hat{e}_x'$ glede na S (oddajnik se oddaljuje od sprejemnika)

$$\boxed{t_1' = \gamma_0 \left(t_1 - \frac{\beta_0}{c_0} x_1\right) = \gamma_0 t_1 = \gamma_0 t}$$

$$\boxed{x_1'(t_1) = \gamma_0 (x_1 - v_0 t_1) = -\gamma_0 v_0 t = -v_0 t_1' = x_1'(t_1')}$$

$$\boxed{t_2' = \gamma_0 \left(t_2 - \frac{\beta_0}{c_0} x_2\right) = \gamma_0 t_2 = \gamma_0 (t + t_0) = \gamma_0 t + \gamma_0 t_0 = t_1' + \gamma_0 t_0}$$

$$\boxed{x_2'(t_2) = \gamma_0 (x_2 - v_0 t_2) = -\gamma_0 v_0 t_2 = -v_0 t_2' = x_2'(t_2')}$$

Ob času t_2' je drugi blisk, ki se giblje s hitrostjo c_0 vzdolž $\hat{e}_x'$, na mestu

$$\boxed{x_1'(t_2') = x_1'(t_1') + c_0 (t_2' - t_1') = -v_0 t_1' + c_0 \gamma_0 t_0}$$

Lorentzove transformacije u^μ

$$v'^2 = v_x'^2 + v_y'^2 + v_z'^2$$

$$= \left[(v_x - v_0)^2 + (v_y^2 + v_z^2)/\gamma_0^2 \right] / \left(1 - \frac{v_x v_0}{c_0^2}\right)^2$$

$$= \left[v_x^2 + v_0^2 - 2 v_x v_0 + (v_y^2 + v_z^2)/\gamma_0^2 \right] / \left(1 - \frac{v_x v_0}{c_0^2}\right)^2$$

$$= \left[v_x^2 \left(\frac{1}{\gamma_0^2} + \beta_0^2 \right) + v_0^2 - 2 v_x v_0 + (v_y^2 + v_z^2)/\gamma_0^2 \right] / \left(1 - \frac{v_x v_0}{c_0^2}\right)^2 \leftarrow \begin{cases} \frac{1}{\gamma_0^2} = 1 - \beta_0^2 \\ \Rightarrow \frac{1}{\gamma_0^2} + \beta_0^2 = 1 \end{cases}$$

$$= \left[(v_x^2 + v_y^2 + v_z^2)/\gamma_0^2 + v_x^2 \beta_0^2 + v_0^2 - 2 v_x v_0 \right] / \left(1 - \frac{v_x v_0}{c_0^2}\right)^2$$

$$= \left[v^2 (1 - \beta_0^2) + v_x^2 \beta_0^2 + v_0^2 - 2 v_x v_0 \right] / \left(1 - \frac{v_x v_0}{c_0^2}\right)^2$$

$$= c_0^2 \left[\beta^2 (1 - \beta_0^2) + \beta_0^2 \frac{v_x^2}{c_0^2} + \beta_0^2 - 2 \frac{v_x}{c_0} \beta_0 \right] / \left(1 - \frac{v_x v_0}{c_0^2}\right)^2 \qquad \beta^2 = \frac{v^2}{c_0^2}$$

$$= c_0^2 \left[\beta^2 (1 - \beta_0^2) + \beta_0^2 \frac{v_x^2}{c_0^2} - 2 \frac{v_x}{c_0} \beta_0 + 1 - (1 - \beta_0^2) \right] / \left(1 - \frac{v_x v_0}{c_0^2}\right)^2$$

$$= c_0^2 \left[\beta^2 (1 - \beta_0^2) - (1 - \beta_0^2) + \left(1 - \frac{\beta_0 v_x}{c_0}\right)^2 \right] / \left(1 - \frac{v_x v_0}{c_0^2}\right)^2$$

$$= c_0^2 \left[\left(1 - \frac{v_x v_0}{c_0^2}\right)^2 - (1 - \beta_0^2)(1 - \beta^2) \right] / \left(1 - \frac{v_x v_0}{c_0^2}\right)^2$$

$$= c_0^2 \left[1 - \frac{(1 - \beta_0^2)(1 - \beta^2)}{\left(1 - \frac{v_x v_0}{c_0^2}\right)^2} \right]$$

Če $v = c_0 \Rightarrow \beta = 1$ in $v'^2 = c_0^2 = v^2$ ✓

$$\Rightarrow \beta'^2 = \frac{v'^2}{c_0^2}$$

$$= 1 - \frac{(1 - \beta_0^2)(1 - \beta^2)}{\left(1 - \frac{v_x v_0}{c_0^2}\right)^2}$$

$$\Rightarrow \quad 1-\beta'^2 = \frac{(1-\beta_0^2)(1-\beta^2)}{\left(1-\frac{v_x v_0}{c_0^2}\right)^2}$$

$$\Rightarrow \boxed{\gamma'} = \frac{1}{\sqrt{1-\beta'^2}} = \frac{\left(1-\frac{v_x v_0}{c_0^2}\right)}{\sqrt{1-\beta_0^2}\sqrt{1-\beta^2}} = \boxed{\gamma\gamma_0\left(1-\frac{v_x v_0}{c_0^2}\right)}$$

$$u^\mu = \begin{bmatrix} u^0 \\ u^1 \\ u^2 \\ u^3 \end{bmatrix} = \begin{bmatrix} \gamma c_0 \\ \gamma v_x \\ \gamma v_y \\ \gamma v_z \end{bmatrix}$$

$$\boxed{u'^0} = \gamma' c_0' = \gamma' c_0 = \gamma_0\gamma\left(1-\frac{v_x v_0}{c_0^2}\right)c_0 = \gamma_0(\gamma c_0 - \beta_0\gamma v_x) = \boxed{\gamma_0(u^0-\beta_0 u^1)}$$

$$\boxed{u'^1} = \gamma' v_x' = \gamma_0\gamma\cancel{\left(1-\frac{v_x v_0}{c_0^2}\right)}\frac{(v_x-v_0)}{\cancel{\left(1-\frac{v_x v_0}{c_0^2}\right)}} = \gamma_0(\gamma v_x - \gamma v_0) = \gamma_0(\gamma v_x - \beta_0\gamma c_0)$$

$$= \boxed{\gamma_0(u^1-\beta_0 u^0)}$$

$$\boxed{u'^2} = \gamma' v_y' = \cancel{\gamma_0}\gamma\cancel{\left(1-\frac{v_x v_0}{c_0^2}\right)}\frac{1}{\cancel{\gamma_0}}\frac{v_y}{\cancel{\left(1-\frac{v_x v_0}{c_0^2}\right)}} = \gamma v_y = \boxed{u^2}$$

$$\boxed{u'^3} = \gamma' v_z' = \cancel{\gamma_0}\gamma\cancel{\left(1-\frac{v_x v_0}{c_0^2}\right)}\frac{1}{\cancel{\gamma_0}}\frac{v_z}{\cancel{\left(1-\frac{v_x v_0}{c_0^2}\right)}} = \gamma v_z = \boxed{u^3}$$

$$\Rightarrow \boxed{u'^\mu = L u^\mu}$$

$\Rightarrow$ ob času t_2' razdalja med bliskoma v S' (valovna dolžina λ')

$$\boxed{\lambda'} = |x_1'(t_2') - x_2'(t_2')|$$

$$= |-v_0 t_1' + c_0 \gamma_0 t_0 + v_0 t_2'|$$

$$= |-v_0 t_1' + c_0 \gamma_0 t_0 + v_0 (t_1' + \gamma_0 t_0)|$$

$$= \gamma_0 (c_0 + v_0) t_0$$

$$= \frac{c_0 + v_0}{\sqrt{1 - \frac{v_0^2}{c_0^2}}} t_0$$

$$= \frac{c_0 + v_0}{\sqrt{c_0^2 - v_0^2}} \overbrace{c_0 t_0}^{\lambda}$$

$$\boxed{= \sqrt{\frac{c_0 + v_0}{c_0 - v_0}} \lambda}$$

ali

$$\boxed{\nu'} = \frac{c_0}{\lambda'} = \sqrt{\frac{c_0 - v_0}{c_0 + v_0}} \frac{c_0}{\lambda} = \boxed{\sqrt{\frac{c_0 - v_0}{c_0 + v_0}} \nu}$$

Če se sprejemnik približuje:

$$\boxed{\begin{aligned} \lambda' &= \sqrt{\frac{c_0 - v_0}{c_0 + v_0}} \lambda \\ \nu' &= \sqrt{\frac{c_0 + v_0}{c_0 - v_0}} \nu \end{aligned}}$$

⑨ Četverec gibalne količine

- $\vec{G} \equiv m\vec{v} \quad \Rightarrow \quad \boxed{p^\mu \equiv m u^\mu} = \begin{bmatrix} m\gamma c_0 \\ m\gamma\vec{v} \end{bmatrix} = \begin{bmatrix} m\gamma c_0 \\ \vec{p} \end{bmatrix}$

- $\boxed{\vec{p} = m\gamma\vec{v}} = m\vec{v}\frac{1}{\sqrt{1-\beta^2}} \quad ; \quad \beta = \frac{v}{c_0}$

$$\beta \ll 1 \Rightarrow \quad \vec{p} \simeq m\vec{v}\left(1+\frac{\beta^2}{2}\right) \simeq m\vec{v} = \vec{G}$$

- $m\gamma c_0 = \frac{1}{c_0} m\gamma c_0^2$

$$\beta \ll 1 \Rightarrow \quad m\gamma c_0 \simeq \frac{1}{c_0} m\left(1+\frac{\beta^2}{2}\right)c_0^2 = \frac{1}{c_0}\Big(mc_0^2 + \underbrace{\tfrac{1}{2}mv^2}_{= W_k \ (=T)}\Big)$$

$$\Rightarrow \quad \boxed{m\gamma c_0^2 = E}$$

$\boxed{mc_0^2 = E_0}$ = mirovna energija

$\boxed{T \equiv E - E_0}$ = kinetična energija $\quad ; \quad \beta \ll 1 : T \simeq \frac{1}{2}mv^2$

$$\Rightarrow \quad \boxed{p^\mu = \begin{bmatrix} \frac{E}{c_0} \\ \vec{p} \end{bmatrix}}$$

$\langle G p^\mu, p^\mu \rangle = m^2 \langle G u^\mu, u^\mu \rangle = m^2 c_0^2$ (= Lor. invarianta)

Po drugi strani:

$$\langle G p^\mu, p^\mu \rangle = \frac{E^2}{c_0^2} - p^2$$

$$\Rightarrow \frac{E^2}{c_0^2} - p^2 = m^2 c_0^2$$

$$\Rightarrow \boxed{E^2 = m^2 c_0^4 + p^2 c_0^2}$$

Četverec gibalne količine sistema

- $p_1^\mu = \begin{bmatrix} \frac{E_1}{c_0} \\ \vec{p}_1 \end{bmatrix}, \; p_2^\mu = \begin{bmatrix} \frac{E_2}{c_0} \\ \vec{p}_2 \end{bmatrix}, \ldots ;$ v opazovalnem sistemu S

$\boxed{p^\mu \equiv \sum_i p_i^\mu}$ četverec opazovanega sistema na začetku

- končno stanje

$p_1'^\mu = \begin{bmatrix} \frac{E_1'}{c_0} \\ \vec{p}_1' \end{bmatrix}, \; p_2'^\mu = \begin{bmatrix} \frac{E_2'}{c_0} \\ \vec{p}_2' \end{bmatrix}, \ldots ;$ v istem opazovalnem sistemu S

$\boxed{p'^\mu \equiv \sum_i p_i'^\mu}$ četverec opazovanega sistema na koncu

Zakon: $\boxed{p'^\mu = p^\mu}$

- četverec gibalne količine (vsaka njegova komponenta posebej) izoliranega sistema se ohranja
- fizikalni zakon (zakon narave)

Invariantna masa sistema

- $P_i^{\mu} = m_i u_i^{\mu}$; četverec gibalne količine za i-ti delec v S'
- Lorentzova transformacija P_i :

$$\boxed{P_i^{\prime\mu}} = m_i' u_i'^{\mu}$$

$$= m_i u_i'^{\mu} \qquad (m_i = \text{skalar} \,;\, m_i' = m_i)$$

$$= m_i L u_i^{\mu}$$

$$= L(m_i u_i^{\mu})$$

$$\boxed{= L P_i^{\mu}}$$

$$\Rightarrow \boxed{P'^{\mu}} = \sum_i P_i'^{\mu}$$

$$= \sum_i L P_i^{\mu}$$

$$= L \sum P_i^{\mu}$$

$$\boxed{= L P^{\mu}}$$

$$\Rightarrow \boxed{\langle G P'^{\mu}, P'^{\mu} \rangle} = \langle G L P^{\mu}, L P^{\mu} \rangle$$

$$= \langle L^T G L P^{\mu}, P^{\mu} \rangle$$

$$= \langle L G L P^{\mu}, P^{\mu} \rangle \qquad (L^T = L)$$

$$\boxed{= \langle G P^{\mu}, P^{\mu} \rangle} \qquad (LGL = G)$$

– količina invariantna na Lorentzove transformacije

$\Rightarrow$ količina $\frac{1}{c_0^2} \langle G P^{\mu}, P^{\mu} \rangle$ tudi invarianten na L.T.

Def. $\boxed{m \equiv \frac{1}{c_0^2} \langle G P^{\mu}, P^{\mu} \rangle}$ invariantna masa opazovanega sistema

Zakon o ohranitvi četverca P^μ v različnih opazovalnih sistemih

S: P_z^μ = četverec gibalne količine opazovanega sistema na začetku

P_k^μ = na koncu

Zakon o ohranitvi P^μ v S:

$$\times L \quad \boxed{P_z^\mu = P_k^\mu}$$

$$\Rightarrow L P_z^\mu = L P_k^\mu$$

$$\Rightarrow \boxed{P_z'^\mu = P_k'^\mu}^{*},$$

kjer sta:

S': $P_z'^\mu = L P_z^\mu$ začetna } gibalna količina sistema, izražene v S'
$P_k'^\mu = L P_k^\mu$ končna }

(Fizikalni) zakon o ohranitvi (četverca) gibalne količine opazovanega sistema ima enako obliko v vseh (inercialnih) opazovalnih sistemih (Einsteinova zahteva - postulat)