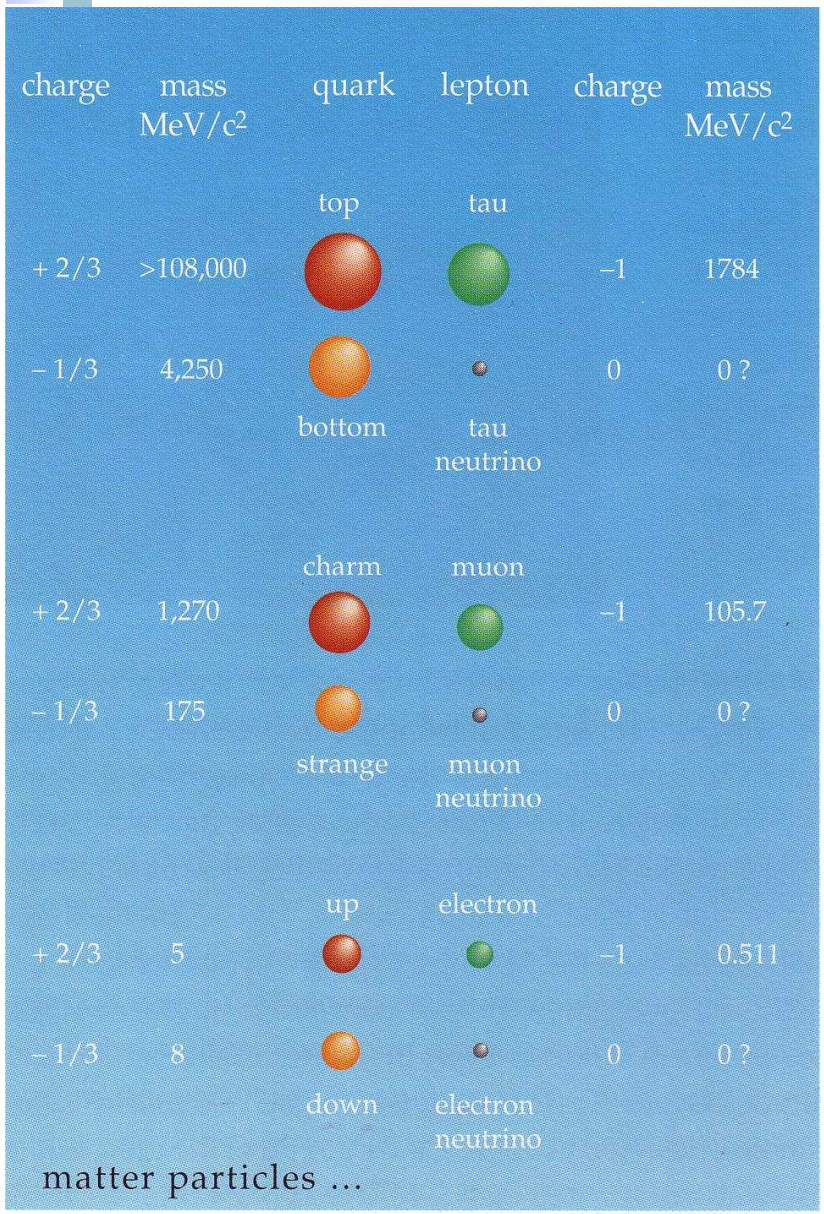


II. (FEČ, Pogl.2) NAČELO SIMETRIJE U FEČ

- KLASIFIKACIJA ČESTICA i OČUVANE VELIČINE
- SIMETRIJE u KLASIČNOJ FIZICI
- RELATIVISTIČKA SIMETRIJA (Vježbe: Relativistička kinematika)

OČUVANE VELIČINE i KLASIFIKACIJA FERMIONA &

BARYONS (Spin $\frac{1}{2}$)

Baryon	Quark content	Charge	Mass	Lifetime	Principal decays
$N\begin{cases} p \\ n \end{cases}$	uud	$+1$	938.280	∞	—
	udd	0	939.573	900	$pe\bar{\nu}_e$
Λ	uds	0	1115.6	2.63×10^{-10}	$p\pi^-$, $n\pi^0$
Σ^+	uus	$+1$	1189.4	0.80×10^{-10}	$p\pi^0$, $n\pi^+$
Σ^0	uds	0	1192.5	6×10^{-20}	$\Lambda\gamma$
Σ^-	dds	-1	1197.3	1.48×10^{-10}	$n\pi^-$
Ξ^0	uss	0	1314.9	2.90×10^{-10}	$\Lambda\pi^0$
Ξ^-	dss	-1	1321.3	1.64×10^{-10}	$\Lambda\pi^-$
Λ_c^+	udc	$+1$	2281	2×10^{-13}	not established

BARYONS (Spin $\frac{3}{2}$)

Baryon	Quark content	Charge	Mass	Lifetime	Principal decays
Δ	uuu, uud, udd, ddd	$+2, +1, 0, -1$	1232	0.6×10^{-23}	$N\pi$
Σ^*	uus, uds, dds	$+1, 0, -1$	1385	2×10^{-23}	$\Lambda\pi$, $\Sigma\pi$
Ξ^*	uss, dss	$0, -1$	1533	7×10^{-23}	$\Xi\pi$
Ω^-	sss	-1	1672	0.82×10^{-10}	ΛK^-, $\Xi^0\pi^-$, $\Xi^-\pi^0$

KLASIFIKACIJA BOZONA

PSEUDOSCALAR MESONS (Spin 0)

Meson	Quark content	Charge	Mass	Lifetime	Principal decays
$\pi^{\pm}$	$u\bar{d}$, $d\bar{u}$	+1, −1	139.569	2.60×10^{-8}	$\mu\nu_\mu$
π^0	$(u\bar{u} - d\bar{d})/\sqrt{2}$	0	134.964	8.7×10^{-17}	$\gamma\gamma$
$K^{\pm}$	$u\bar{s}$, $s\bar{u}$	+1, −1	493.67	1.24×10^{-8}	$\mu\nu_\mu$, $\pi^{\pm}\pi^0$, $\pi^{\pm}\pi^{\pm}\pi^{\mp}$
K^0, $\bar{K}^0$	$d\bar{s}$, $s\bar{d}$	0, 0	497.72	K_S^0 0.892×10^{-10} K_L^0 5.18×10^{-8}	$\pi^+\pi^-$, $\pi^0\pi^0$ $\pi e\nu_e$, $\pi\mu\nu_\mu$, $\pi\pi\pi$
η	$(u\bar{u} + d\bar{d} - 2s\bar{s})/\sqrt{6}$	0	548.8	7×10^{-19}	$\gamma\gamma$, $\pi^0\pi^0\pi^0$, $\pi^+\pi^-\pi^0$
η'	$(u\bar{u} + d\bar{d} + s\bar{s})/\sqrt{3}$	0	957.6	3×10^{-21}	$\eta\pi\pi$, $\rho^0\gamma$
$D^{\pm}$	$c\bar{d}$, $d\bar{c}$	+1, −1	1869	9×10^{-13}	$K\pi\pi$
D^0, $\bar{D}^0$	$c\bar{u}$, $u\bar{c}$	0, 0	1865	4×10^{-13}	$K\pi\pi$
$F^{\pm}$ (now $D_s^{\pm}$)	$c\bar{s}$, $s\bar{c}$	+1, −1	1971	3×10^{-13}	not established
$B^{\pm}$	$u\bar{b}$, $b\bar{u}$	+1, −1	5271	14×10^{-13}	D + ?
B^0, $\bar{B}^0$	$d\bar{b}$, $b\bar{d}$	0, 0	5275		
η_c	$c\bar{c}$	0	2981	6×10^{-23}	$KK\pi$, $\eta\pi\pi$, $\eta'\pi\pi$

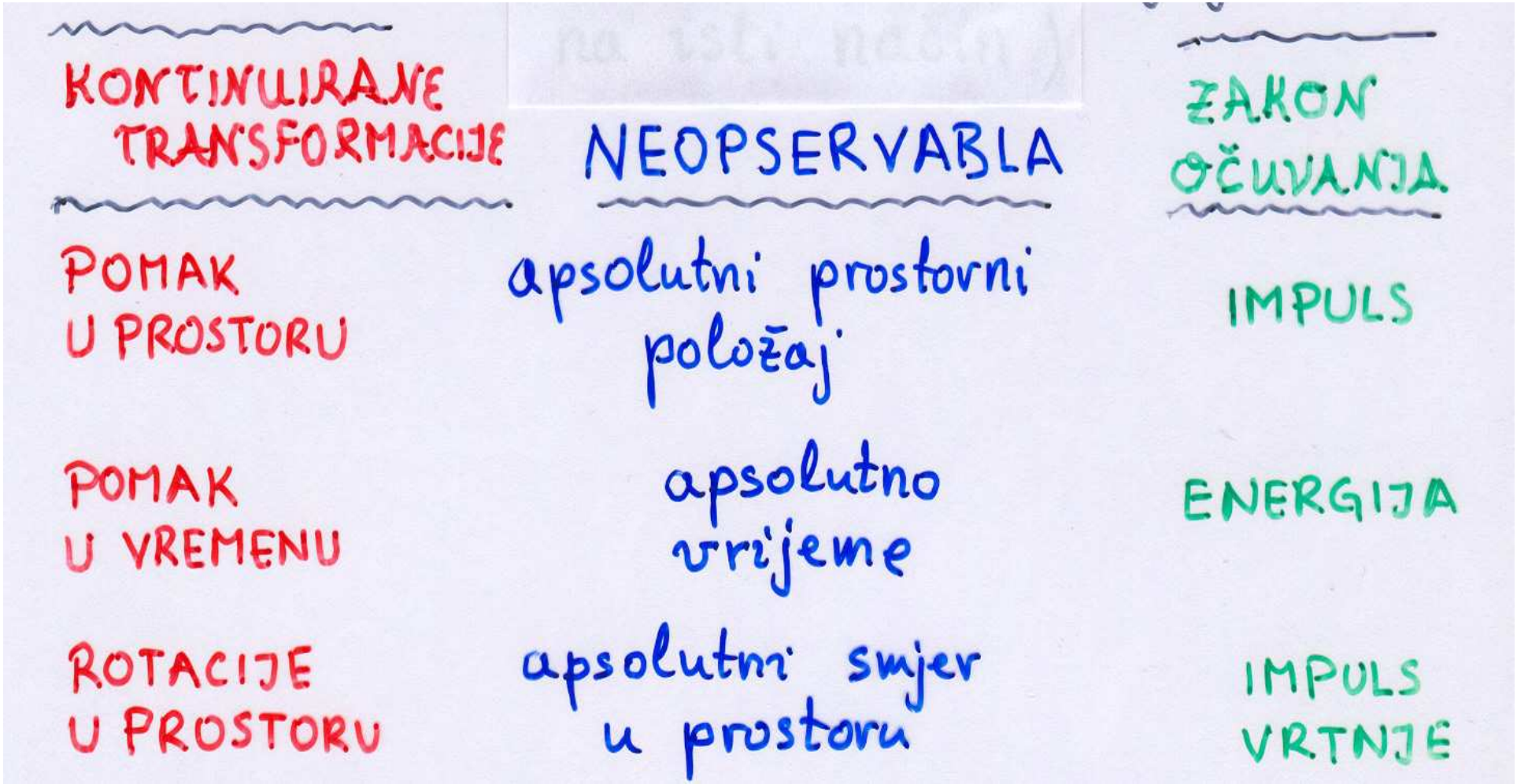
VECTOR MESONS (Spin 1)

Meson	Quark content	Charge	Mass	Lifetime	Principal decays
ρ	$u\bar{d}$, $d\bar{u}$, $(u\bar{u} - d\bar{d})/\sqrt{2}$	+1, −1, 0	770	0.4×10^{-23}	$\pi\pi$
K^*	$u\bar{s}$, $s\bar{u}$, $d\bar{s}$, $s\bar{d}$	+1, −1, 0, 0	892	1×10^{-23}	$K\pi$
ω	$(u\bar{u} + d\bar{d})/\sqrt{2}$	0	783	7×10^{-23}	$\pi^+\pi^-\pi^0$, $\pi^0\gamma$
ϕ	$s\bar{s}$	0	1020	20×10^{-23}	K^+K^-, $K^0\bar{K}^0$
J/ψ	$c\bar{c}$	0	3097	1×10^{-20}	e^+e^-, $\mu^+\mu^-$, 5π, 7π
D^*	$c\bar{d}$, $d\bar{c}$, $c\bar{u}$, $u\bar{c}$	+1, −1, 0, 0	2010	$>1 \times 10^{-22}$	$D\pi$, $D\gamma$
Υ	$b\bar{b}$	0	9460	2×10^{-20}	$\tau^+\tau^-$, $\mu^+\mu^-$, e^+e^-

SIMETRIČNI ZAHVAT

- **KOJI NE MIJENJA FIZIKALNI SUSTAV (svi se procesi odvijaju na isti način)**
- **POVIJEST NOVIJE FIZIKE – izučavanje simetrija i njihovih narušenja**
- **VEZA SIMETRIJA i očuvanih veličina, kao prvi korak**

Simetrije Newtonovog prostora i vremena:



RELATIVISTIČKA SIMETRIJA

(FEČ § 2.2, str. 61)

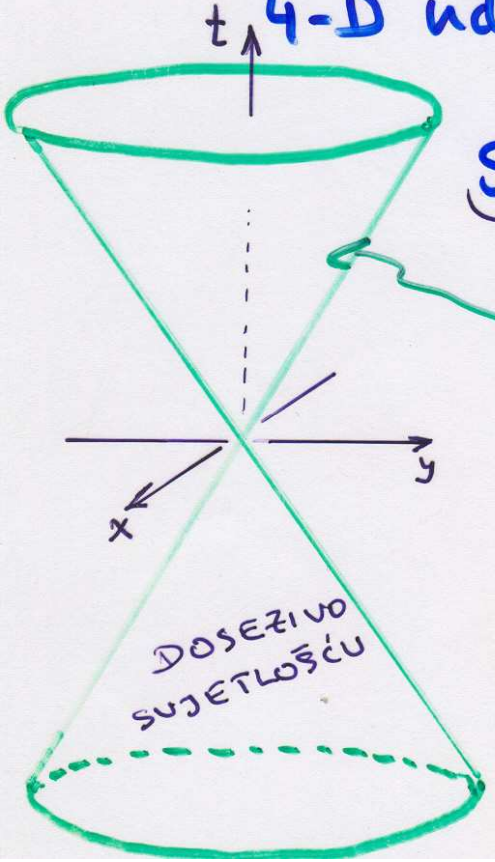
Simetrija specijalne relativnosti

- ravnopravno pojavljivanje PROSTORA i VREMENA
- ostvarena u svijetu ELEMENTARNIH ČESTICA

SIMETRIJA	TRANSFORMACIJA	NEOPSERVABLA
Lorentzova	4-D rotacije $x \to \Lambda x$	apsolutna brzina sustava

4-D udaljenost / Pitagorin poučak

$$S^2 = c^2t^2 - (x^2+y^2+z^2) \begin{cases} > \\ = \\ < \end{cases} 0$$



svjetlosni stožac

PODSJETNIK NA RELATIVISTIČKE INVARIJANTE

$$g_{\mu\nu} = g^{\mu\nu} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & -1 \end{pmatrix}$$

$$x^2 = x^\mu x_\mu = g_{\mu\nu} x^\mu x^\nu = (x^0)^2 - (\vec{x})^2$$

$$\frac{\partial}{\partial x^\mu} \equiv \partial_\mu = \left(\frac{1}{c}\frac{\partial}{\partial t}, \nabla \right),$$

$$\frac{\partial}{\partial x_\mu} \equiv \partial^\mu = \left(\frac{1}{c}\frac{\partial}{\partial t}, -\nabla \right)$$

$$\Box = \partial_\mu \partial^\mu = \frac{1}{c^2}\left(\frac{\partial}{\partial t}\right)^2 - \left(\frac{\partial}{\partial \vec{x}}\right)^2$$

$$p^\mu = i\hbar \frac{\partial}{\partial x_\mu} = \left(i\frac{\hbar}{c}\frac{\partial}{\partial t}, -i\hbar\nabla \right)$$

$$p_\mu p^\mu = \frac{E^2}{c^2} - \vec{p}^{\,2} = m^2 c^2$$

LORENTZOVE TRANSFORMACIJE KAO ROTACIJE U 4-PROSTORU

- **PASIVNA I AKTIVNA TRANSFORMACIJA**

$$
\begin{aligned}
x'^0 &= \gamma(x^0 - \beta x^1) \\
x'^1 &= \gamma(x^1 - \beta x^0) \\
x'^2 &= x^2 \\
x'^3 &= x^3 \, .
\end{aligned}
\qquad
x'^\mu = \sum_{\nu=0}^{3} \Lambda^\mu_\nu x^\nu \equiv \Lambda^\mu_\nu x^\nu
$$

$$
\Lambda = \begin{pmatrix} \gamma & -\gamma\beta & 0 & 0 \\ -\gamma\beta & \gamma & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}
\qquad
\Lambda_1 = \begin{pmatrix} \gamma & \gamma\beta_1 & 0 & 0 \\ \gamma\beta_1 & \gamma & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}
$$

ROTACIJE i POTISCI

$$\beta_j'' = \frac{\beta_j' + \beta_j}{1 + \beta_j' \beta_j}$$

UVOĐENJEM RAPIDITETA

$$\beta_j = \text{th}\,\zeta_j \qquad\qquad \gamma = \text{ch}\,\zeta_j$$

$$\zeta_j'' = \text{Arth}\,\beta_j'' = \text{Arth}\,\beta_j' + \text{Arth}\,\beta_j = \zeta_j' + \zeta_j$$

$$\begin{aligned} x_j' &= x_j\,\text{ch}\,\zeta_j + t\,\text{sh}\,\zeta_j, \\ x_k' &= x_k \qquad\qquad \text{za } k \neq j \\ t' &= x_j\,\text{sh}\,\zeta_j + t\,\text{ch}\,\zeta_j\ . \end{aligned}$$

$$\Lambda_3 = \begin{pmatrix} \text{ch}\,\zeta & 0 & 0 & \text{sh}\,\zeta \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ \text{sh}\,\zeta & 0 & 0 & \text{ch}\,\zeta \end{pmatrix}$$

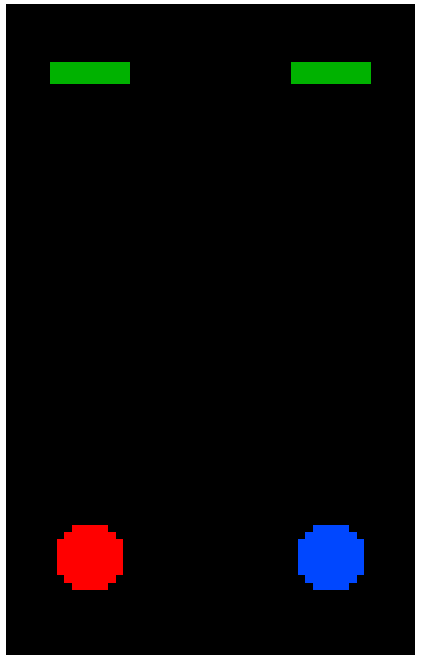
Neobična svojstva prostora-vremena STR

- opažanje ***dilatacije vremena***
- opažanje ***kontrakcije dužina***
- ***ekvivalentnost*** mase i energije

relativistički učinci određeni Lorentzovim faktorom, gama:

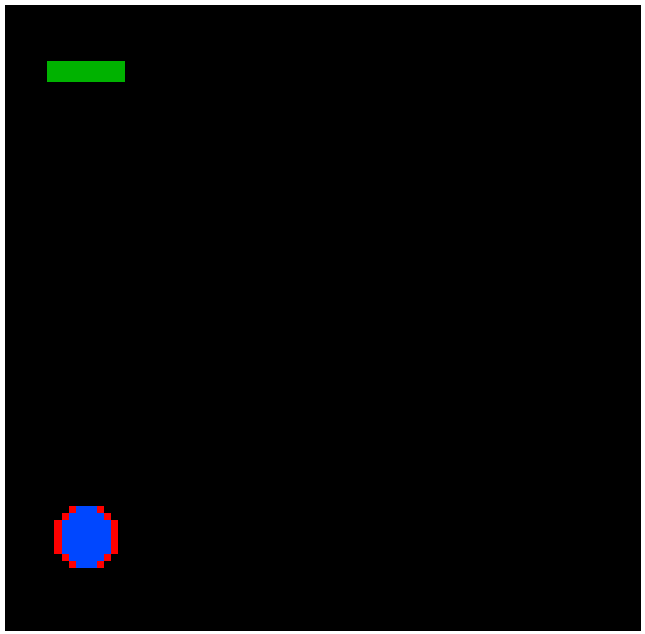
$$\gamma = \frac{1}{\sqrt{1 - v^2/c^2}}$$

Dilatacija vremena



Dok su u relativnom mirovanju **Mirko** i **Žurko** se slažu da njihovi satovi tik-takaju istom mjerom

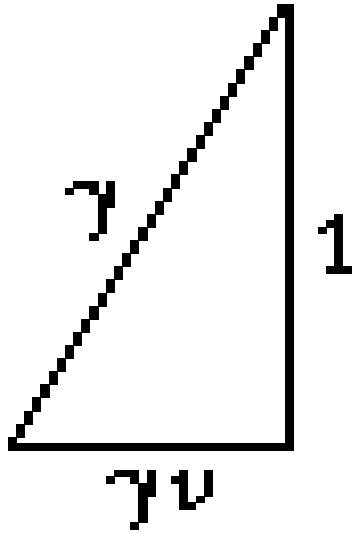
Žurkov sat, potisnut okomito na zraku sata,
tik-taka jednako kao prije



S gledišta Mirka, svjetlost Žurkova sata mora prijeći dulji put. S obzirom na konstantnost brzine svjetlosti, to zahtijeva dulji tik-tak (Žurkov sat djeluje usporeno u odn. na Mirkov)

Nađimo faktor γ za koji je usporen Žurkov sat

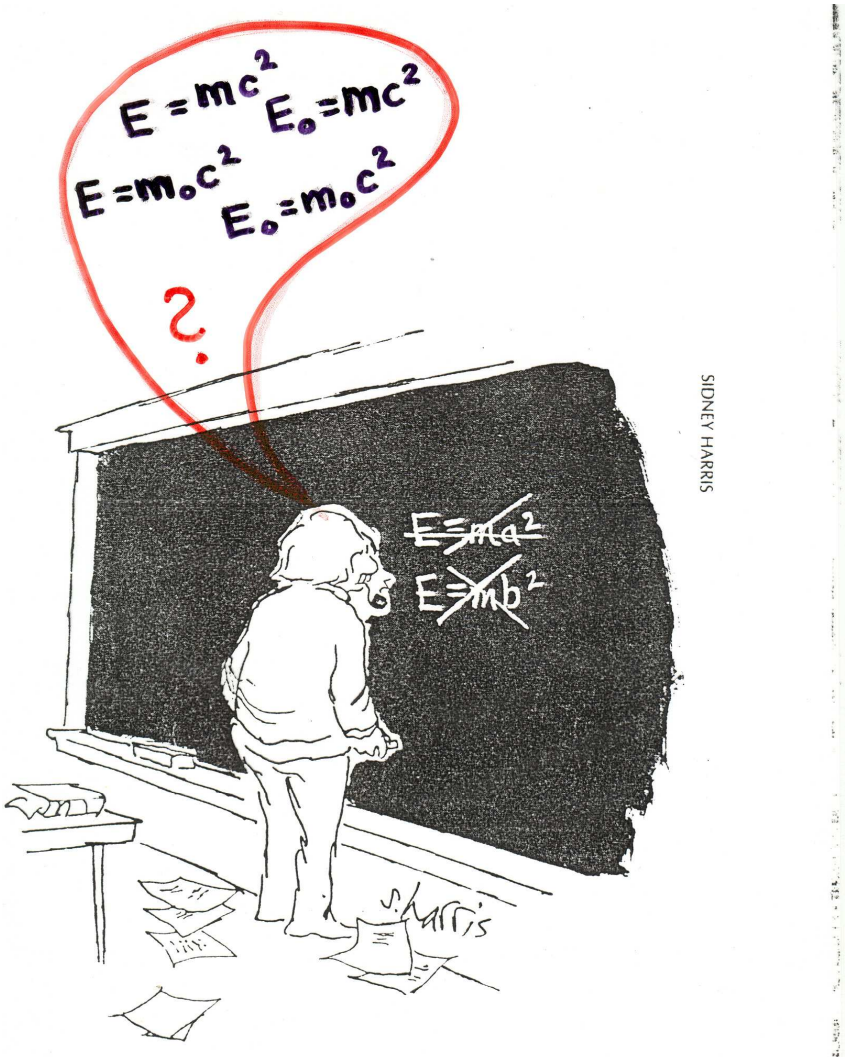
Na početku se oba slože da su zrcala udaljena 1 “tik” (okomita stranica u jedinicama gdje je c=1);



Mirko je uvjeren da svjetlost prevali udaljenost od Žurka do Žurkova zrcala koja iznosi γ “tika” (tijekom kojeg se Žurko brzine v pomakne za γv).

Pitagorin teorem vodi na čuvenu Lorentzovu formulu za γ!

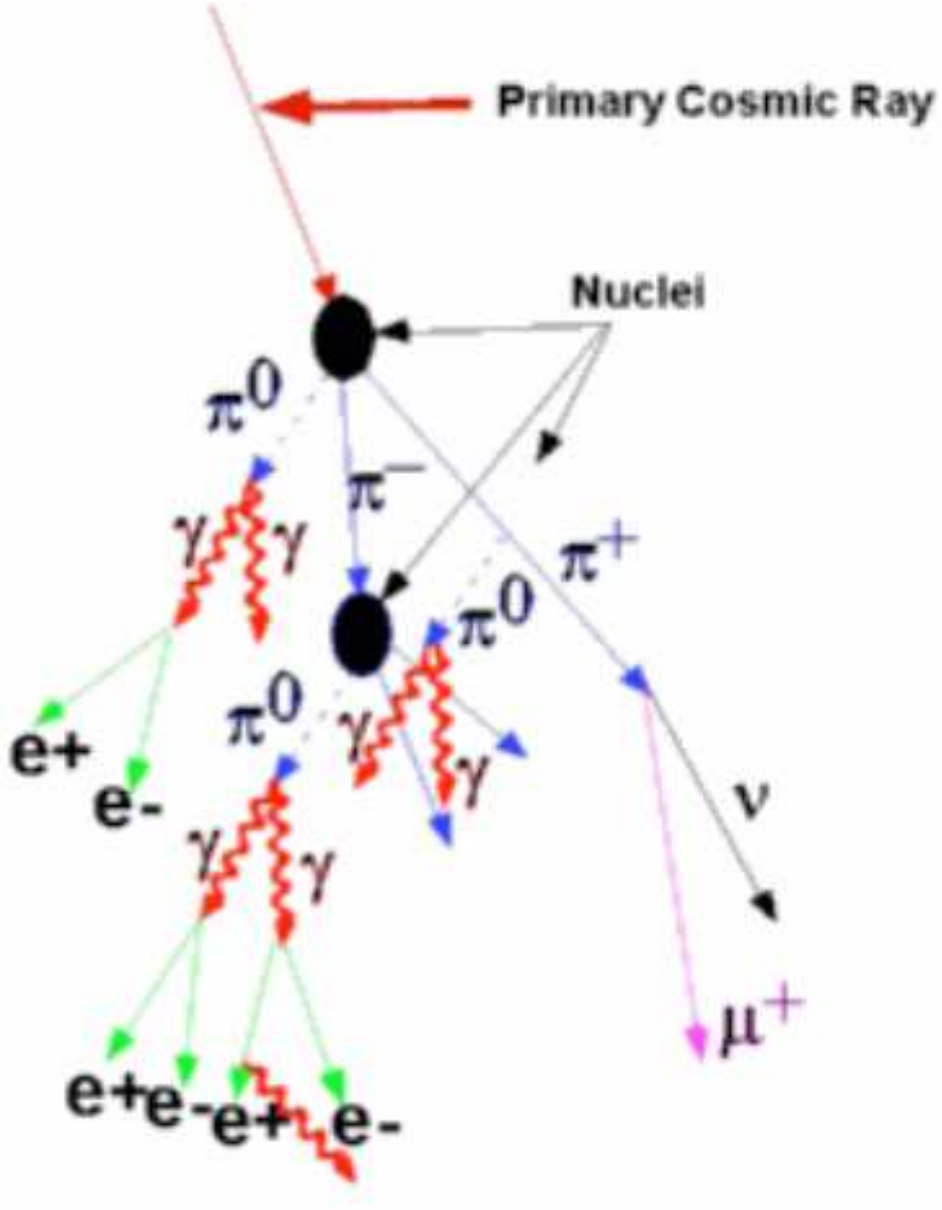
Koja je formula ispravna?



RELATIVISTIČKA INVARIJANTNOST

opažanje
dilatacije vremena
opažanje
kontrakcije dužina
ekvivalentnost
mase i energije

Primjer: vrijeme života miona



RELATIVISTIČKA KOVARIJANTNOST

Primjer kovarijantnog zapisa zakona prirode

Maxwellov zapis elektromagnetizma FEČ I str. 79

$$\frac{\partial E_x}{\partial x} + \frac{\partial E_y}{\partial y} + \frac{\partial E_z}{\partial z} = 4\pi\rho \qquad \nabla\cdot\vec{E} = 4\pi\rho$$

$$\left.\begin{aligned} \frac{\partial B_x}{\partial y} - \frac{\partial B_y}{\partial x} &= \frac{4\pi}{c} j_z + \frac{1}{c}\dot{E}_z \\ \frac{\partial B_y}{\partial z} - & \\ \frac{\partial B_z}{\partial x} - & \end{aligned}\right\} \quad \nabla\times\vec{B} = \frac{4\pi}{c}\vec{j} + \frac{1}{c}\dot{\vec{E}}$$

$$\partial_\mu F^{\mu\nu} = \frac{4\pi}{c} j^\nu$$

$$\frac{\partial B_x}{\partial x} + \frac{\partial B_y}{\partial y} + \frac{\partial B_z}{\partial z} = 0 \qquad \nabla\cdot\vec{B} = 0$$

$$\left.\begin{aligned} \frac{\partial E_x}{\partial y} - \frac{\partial E_y}{\partial x} &= -\frac{1}{c}\dot{B}_z \\ \frac{\partial E_y}{\partial z} - & \\ \frac{\partial E_z}{\partial x} - & \end{aligned}\right\} \quad \nabla\times\vec{E} = -\frac{1}{c}\dot{\vec{B}}$$

$$\partial_\mu \tilde{F}^{\mu\nu} = 0$$

Einsteinove jednadžbe OTR $\qquad G_{\mu\nu} = \varkappa T_{\mu\nu}$