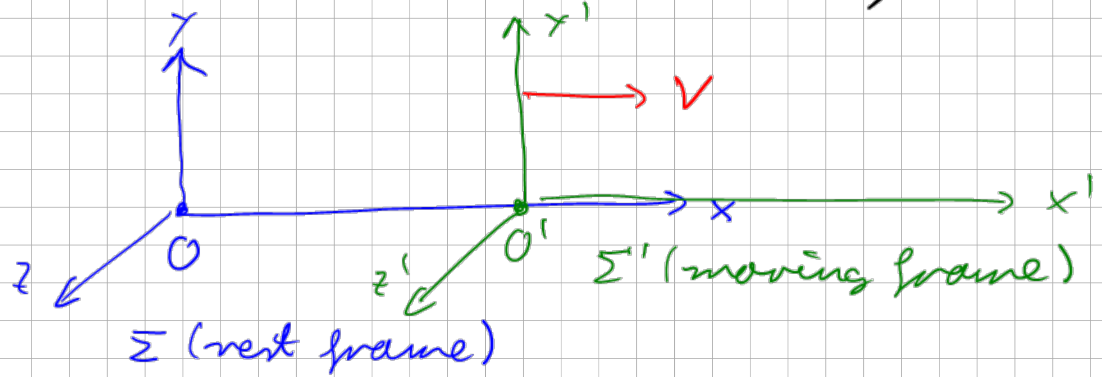
1 Special Relativity:

original notion: space and time are absolute observables.

1.1 Galilei:

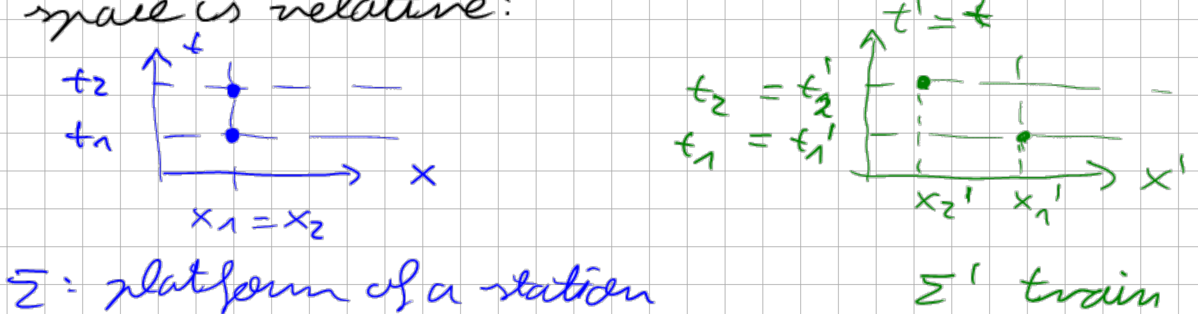
- transformation between two reference frames moving with a constant velocity v uniformly with respect to each other:



Galilei transformation

$$t = t' \quad \text{(still absolute time)}$$
$$x = x' + v t'$$
$$y = y'$$
$$z = z'$$

- space is relative:



$$\begin{cases} x_2 = x_2' + v t_2' \\ x_1 = x_1' + v t_1' \end{cases}$$

$$x_2' = x_1' - v\underbrace{(t_2' - t_1')}_{>0} < x_1'$$

- iteration of two Galilei transformations:
  Galilei addition theorem of velocities: $v = v' + v''$
- all Galilei transformations fulfill a group structure

- Outlook: the understanding of space and time changes
  - > for large velocities: special relativity
  - > for strong gravitational fields: general relativity

1.2 Einstein Postulates:

(E1) Relativity Principle:

There exist inertial systems, i.e. reference frame in which forcefree bodies move both linearly and uniformly. In all inertial systems the laws of nature have one and the same form.

- (E1) represents an extension of the Galilei relativity principle, which only covers mechanical laws, to all laws of nature, i.e. also to electrodynamics.

- Problem: mechanics invariant under Galilei transformations, whereas electrodynamics is invariant under Lorentz transformations.

(E2) Principle of the constance of light velocity:

In all inertial systems the light velocity $c = 2.99792458 \cdot 10^8\ m/s$ has one and the same value.

- light is fast: distance to moon $\hat{=}$ 1.3 s
- experiment from Michelson and Morley (1881, 1907):

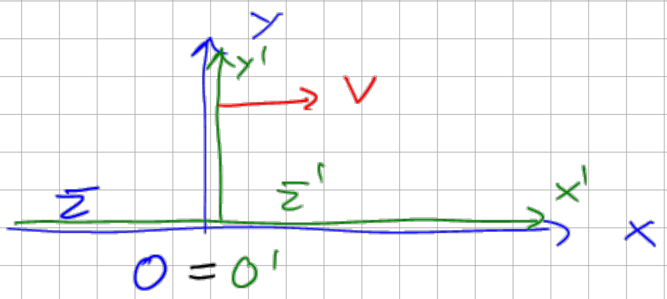
motion of earth does not change the velocity with which light propagates

- immediate discrepancy with Galilei addition theorem of velocities

$v = c\,,\ v' = v > 0 \implies V' = c + v > c$ not possible

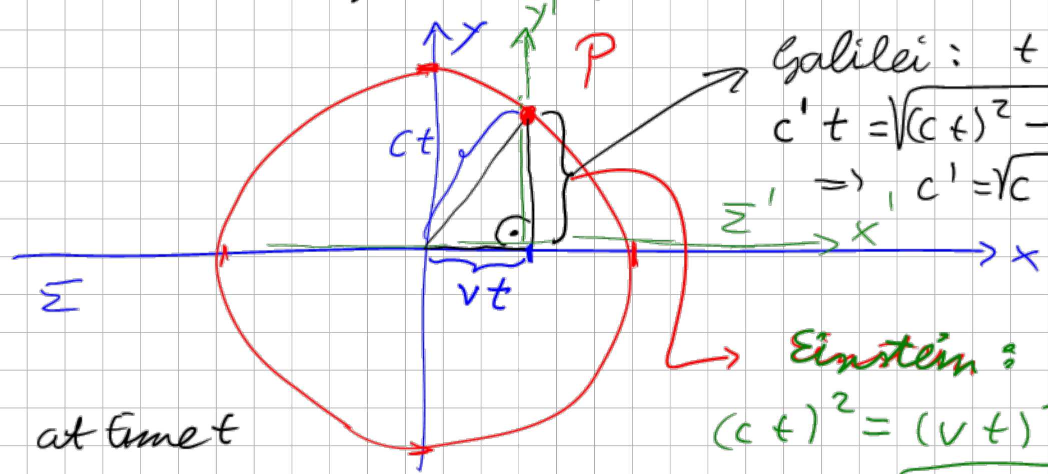
1.3 Time Dilatation:

gedanken experiment: initialization of light signal at $O = O'$ at $t = t' = 0$



synchronization

$t = t'$



at time t

Galilei: $t = t'$

$c' t = \sqrt{(ct)^2 - (vt)^2}$

$\implies c' = \sqrt{c^2 - v^2}$

Einstein: ct'

$(ct)^2 = (vt)^2 + (ct')^2$

$t' = \sqrt{1 - \frac{v^2}{c^2}}\, t < t$

Clock in moving frame Σ' moves slower than in rest frame Σ

$\implies$ time dilatation $\implies$ time is no longer absolute

1.4 Myon Experiment (Rossi, Hall: 1941)

myon: like electron, but heavier $m_\mu = 207\, m_e$

tauon: $m_\tau \approx 3500\, m_e$

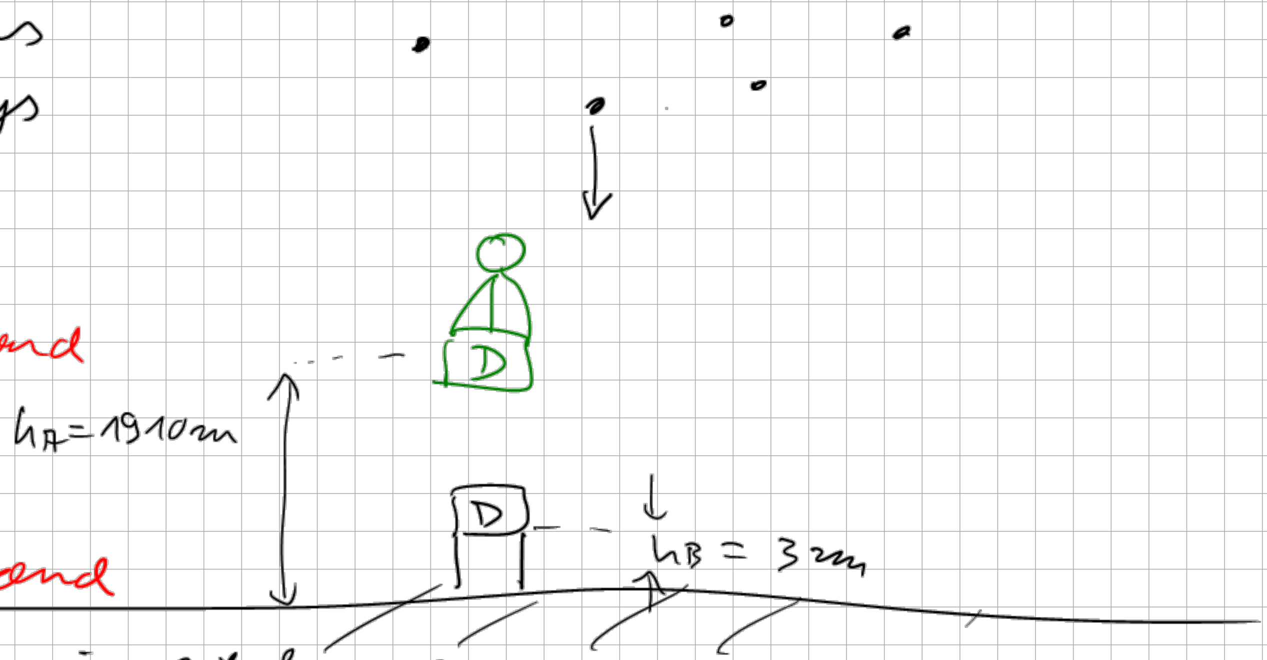
decay of myon: $\mu^- \rightarrow e^- + \overline{\nu_e} + \nu_\mu$ (weak interactions)

average life time of myon: $t_0 = 2.2\,\mu s$

generation of myons
due to cosmic rays

detector A
≙ 563 myons per second
($v/c \approx 0.99\,52$)

detector B
≙ 408 myons per second



- fall time of myons in rest frame

$$t = \frac{h_A - h_B}{v} = 6.4\,\mu s$$

- expected myon number per second:

$$N(t) = N_0\, e^{-\frac{t}{t_0}} = 563\, e^{-\frac{6.4\,\mu s}{2.2\,\mu s}} \approx 31$$

- fall time of myons in moving frame:

$$N(t') = N_0\, e^{-\frac{t'}{t}} \Rightarrow t' = t_0 \ln \frac{N_0}{N(t')} = 2.2\,\mu s \ln \frac{563}{408} \approx 0.71\,\mu s$$

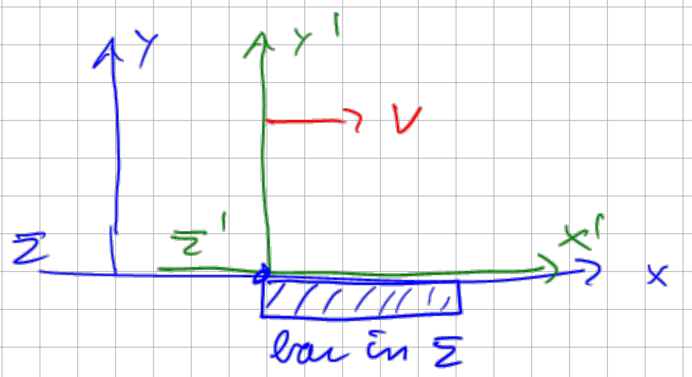
$$\Rightarrow \text{time dilatation: } \frac{t'}{t} = \frac{0.71}{6.4} \approx 0.11$$

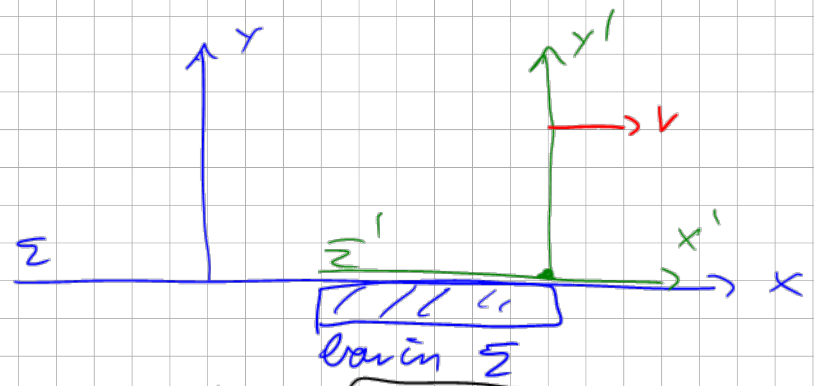
- velocity of velocity:

$$\frac{t'}{t} = \sqrt{1 - \frac{v^2}{c^2}} \Rightarrow \frac{v}{c} = \sqrt{1 - \left(\frac{t'}{t}\right)^2} \approx 0.994$$

1.5 Length Contraction:

Consequence of time dilatation for distance measurements





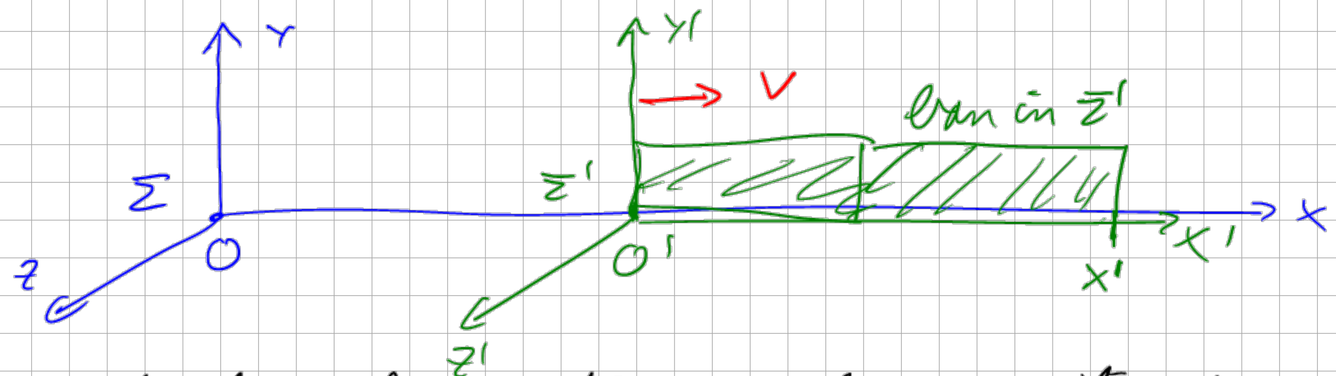
distance in Σ: $x = v\,t$

distance in Σ': $x' = v\,t'$

$$\left.\begin{array}{l} x = v\,t \\ x' = v\,t' \end{array}\right\} \quad \frac{x'}{x} = \frac{t'}{t} = \sqrt{1 - \frac{v^2}{c^2}} \Rightarrow \text{length contraction}$$

illustration: bike ride in Tübingen (Hanns Ruder)

1.6 Lorentz transformation:



standard configuration: synchronization $t = t'$ at $O = O'$

1) description of O' in Σ: $\left.\frac{dx}{dt}\right|_{x'=0} = v$ ✓

2) resting bar in Σ': distance from O' to x' is contracted in Σ with

factor $\sqrt{1-\frac{v^2}{c^2}}$

1.) + 2.) $x = vt + x' \underbrace{\sqrt{1-\frac{v^2}{c^2}}}$