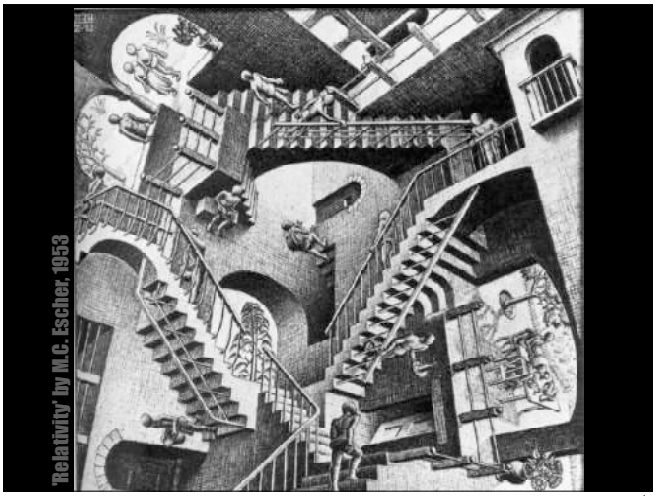


Testing relativistic time dilation with fast stored ions

Gerald Gwinner University of Manitoba

The velocities we experience in daily life are so low that the theory of special relativity plays no role

Example: the addition of velocities

v_{train} = 200 km/h
$v_{passenger}$ = 5 km/h
v_{total} = 205 km/h

Very different at 'high' velocities

Gedankenexperiment: Enterprise travels at v = c/2 = 150 000 km/sec towards Klingon ship and fires photon torpedo
At what speed do the Klingons see the photon torpedo approach?

450 000 km/sec ?

Very different at 'high' velocities

Gedankenexperiment: Enterprise travels at v = c/2 = 150 000 km/sec towards Klingon ship and fires photon torpedo
At what speed do the Klingons see the photon torpedo approach?

450 000 km/sec ?

No, with
300 000 km/sec !

The central principle of the theory of special relativity (SR):

The speed of light does not depend on the motion of the source or the observer and its value in vacuum is always

c = 299 792.458 km/sec

From this principle, alle laws of SR can be derived

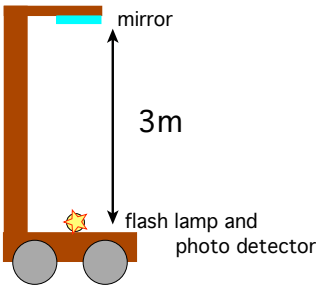
A fascinating manifestation of the theory of special relativity is the phenomenon of

time dilation

i.e. the fact, that moving clocks tick more slowly

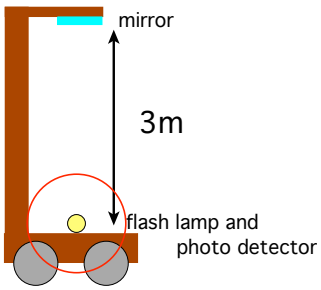
There is no absolute time!

t=0

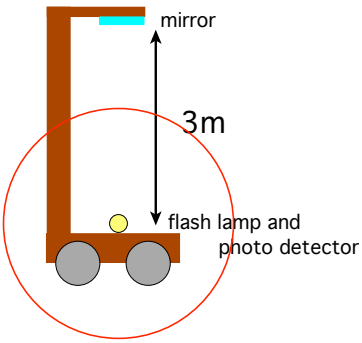


The round-trip time for light is the 'tick' of this clock

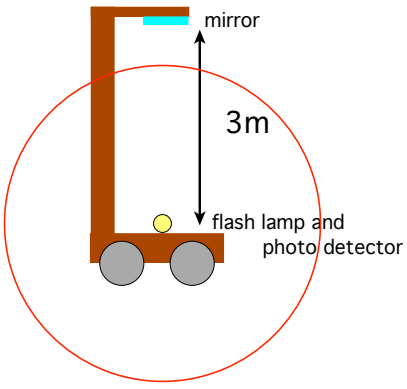
t=2.5 nsec



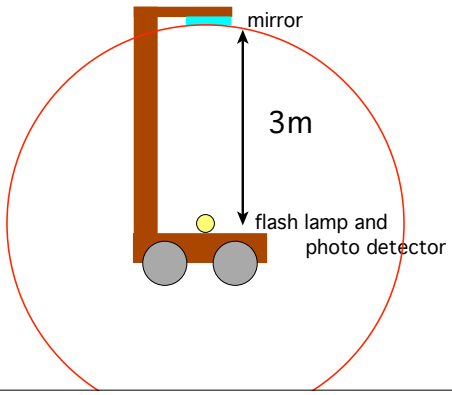
t=5.0 nsec

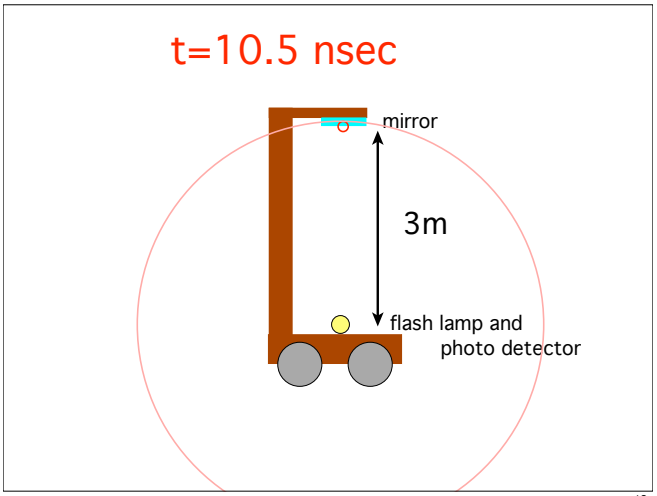


t=7.5 nsec



t=10.0 nsec





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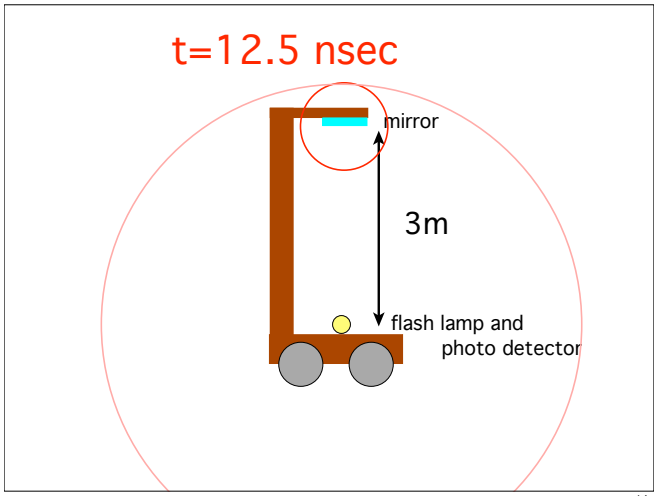

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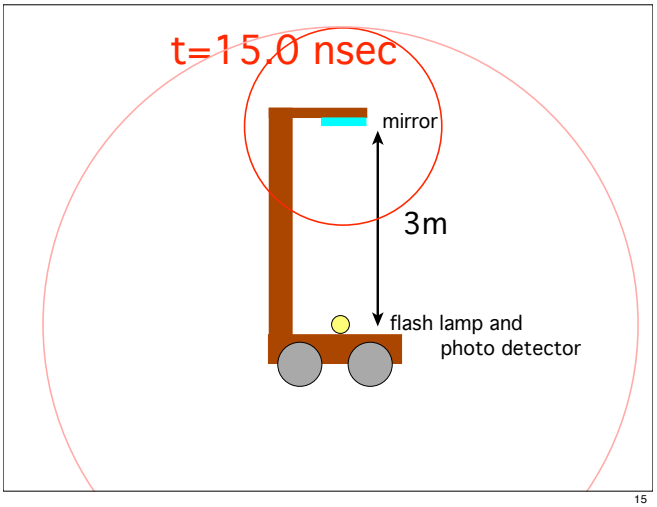

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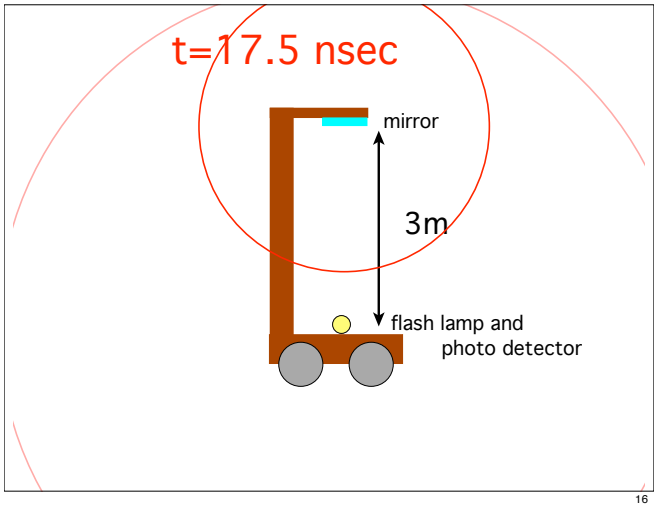

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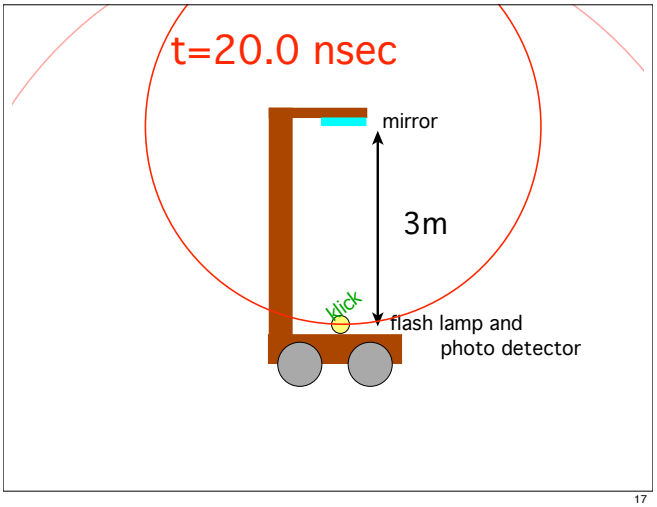

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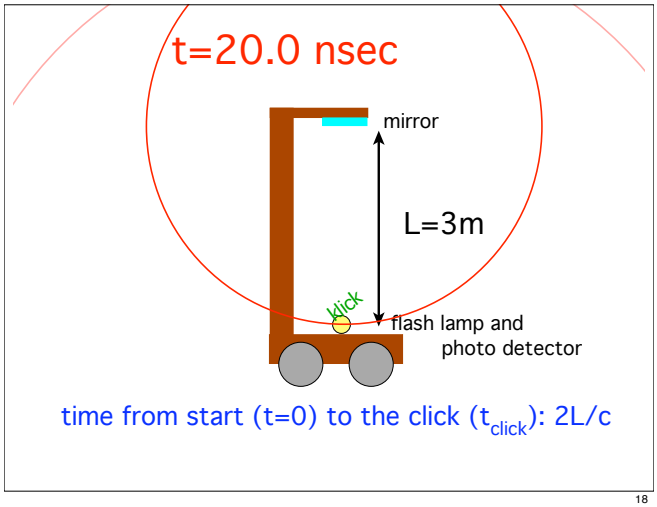

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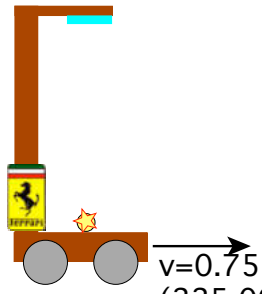
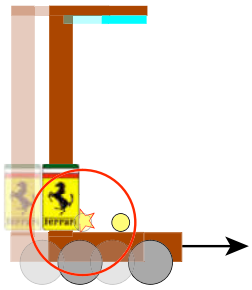
t=0



v=0.75 c
(225 000 km/sec)

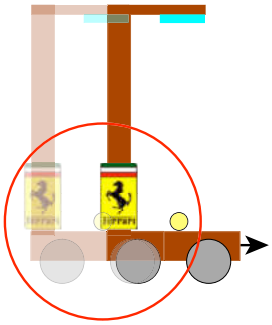
19

t=2.5 nsec



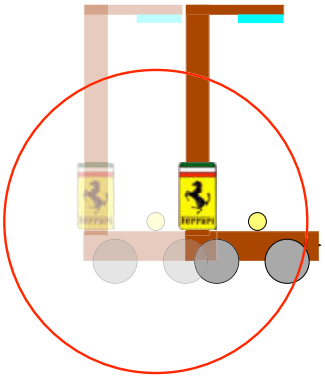
20

t=5.0 nsec



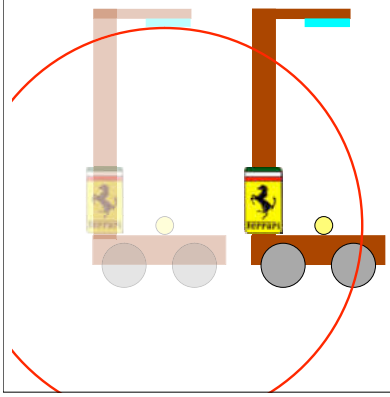
21

t=7.5 nsec



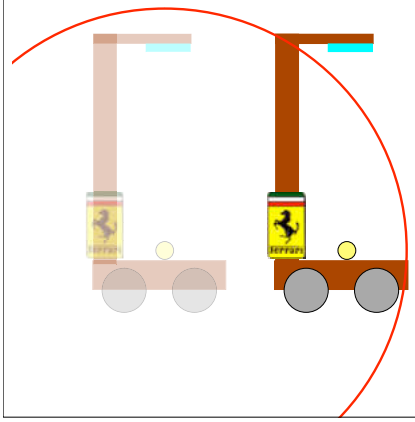
22

t=10.0 nsec



23

t=12.5 nsec



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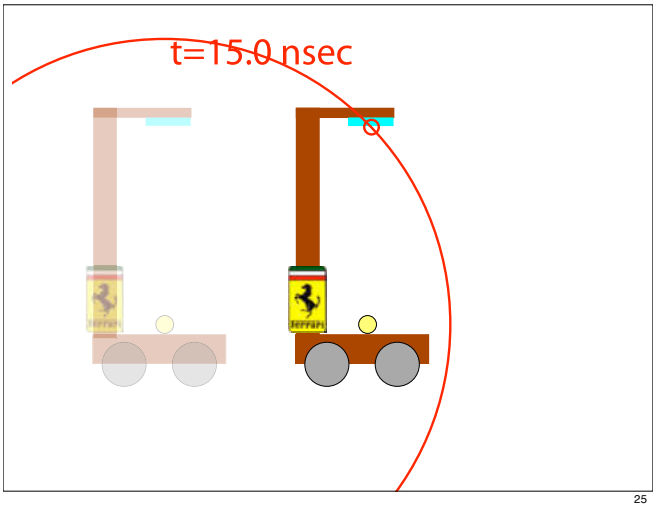

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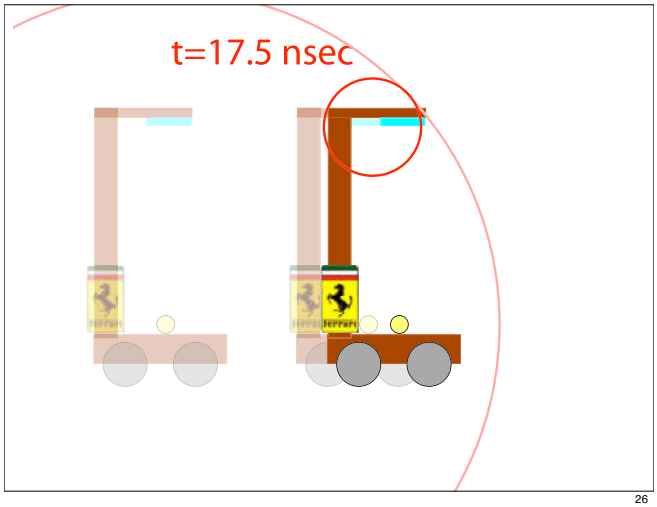

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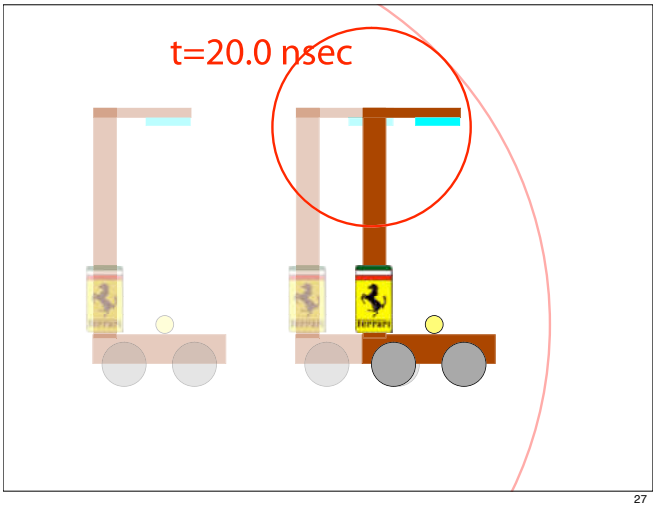

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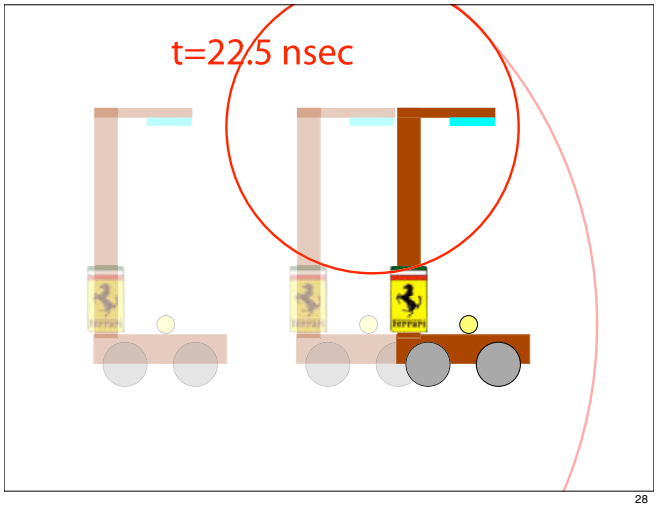

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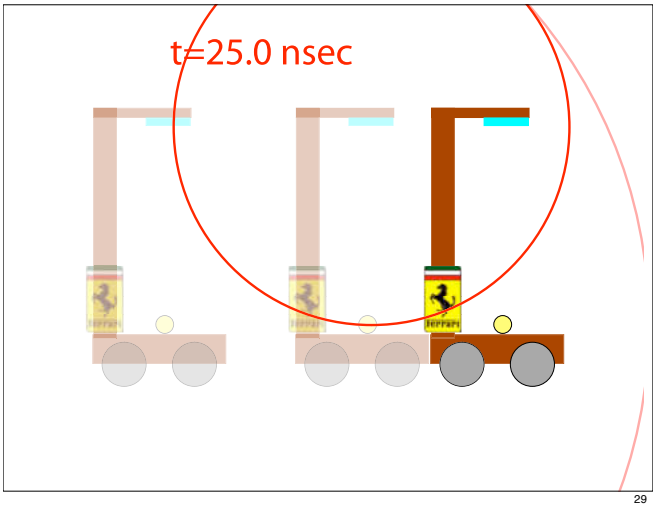

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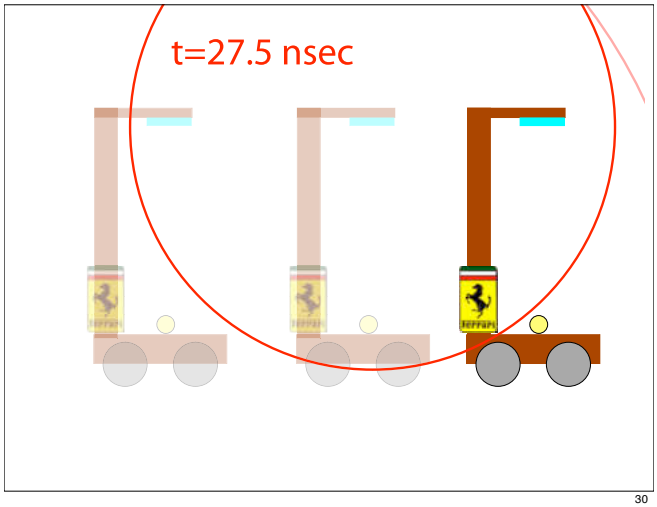

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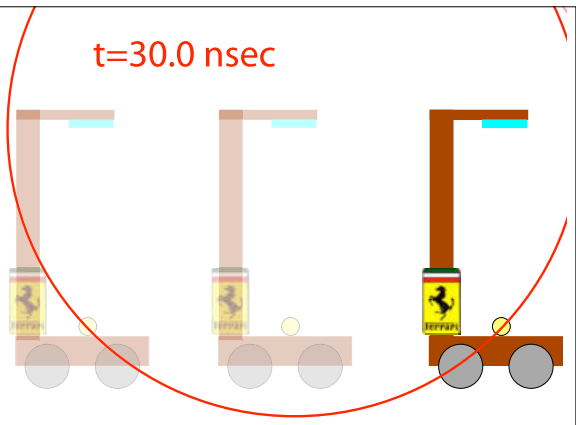
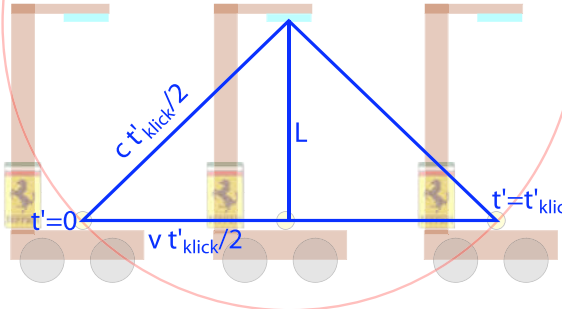
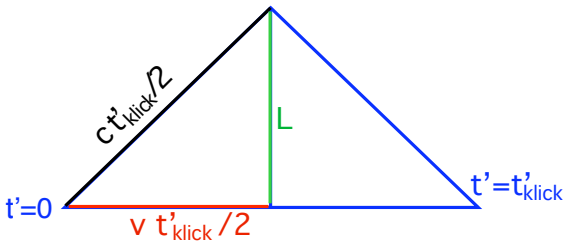




from experiment with car at rest we know:

$L = ct_{click}/2$

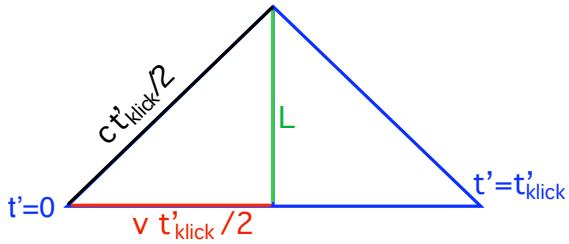


Pythagoras:

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

from experiment with car at rest we know:

$L = ct_{click}/2$



Pythagoras:

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

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

Solve for t' :

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

i.e. for an observer moving with respect to the clock, it ticks more slowly, by the time dilation factor

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

The size of the effect:

	km/sec	time dilation
space craft	5	1.000 000 000 14
0.5 c	150 000	1.15
0.75 c	225 000	1.51
electrons in the storage ring LEP at CERN at 90 Gev	almost 300 000	180 000

Tests with "real" (macroscopic) clocks

Atomic clocks in a plane(1970)

after 60 hour flight:

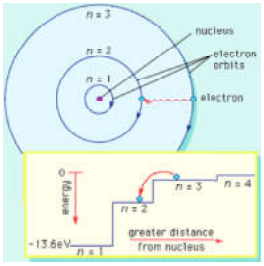
53 nsec

difference to clock on ground

accurate tests of SR need much faster clocks

Atomic and subatomic particles as clocks

Quantum mechanics: energy levels in atoms are discrete (Bohr model)

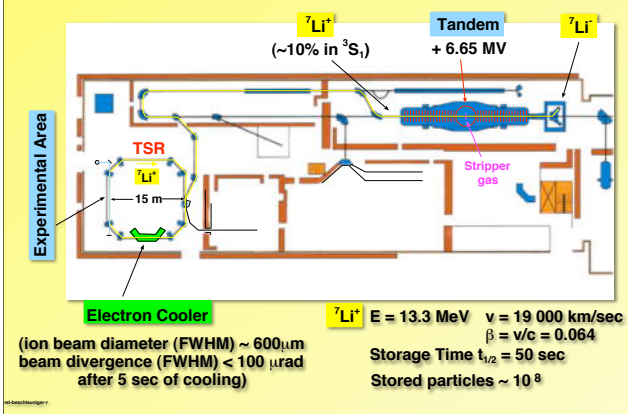


$E = h\nu$

Frequency ν of excitations of atomic levels are our most accurate clocks

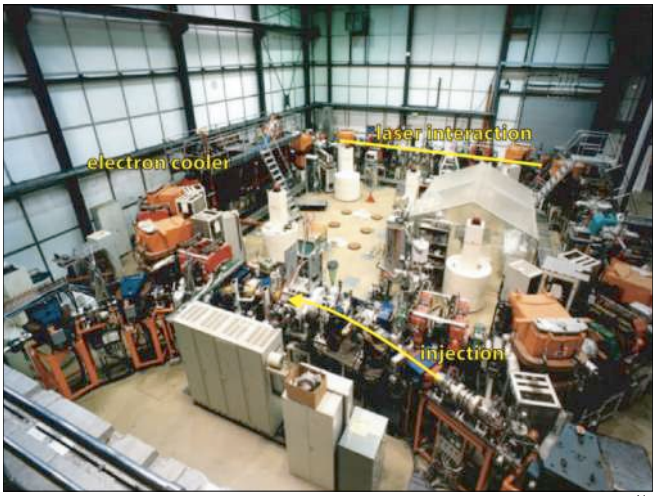
Max Planck Institute for Nuclear Physics
Heidelberg, Germany

The MPI-K Accelerator Facility

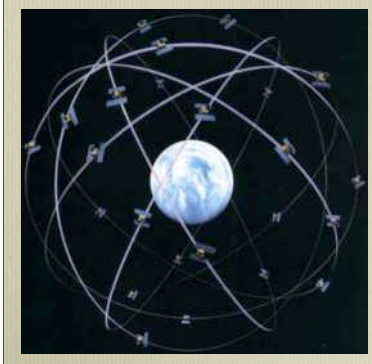


(ion beam diameter (FWHM) ~ 600μm
beam divergence (FWHM) < 100 μrad
after 5 sec of cooling)

$^7Li^+$ E = 13.3 MeV v = 19 000 km/sec
β = v/c = 0.064
Storage Time $t_{1/2}$ = 50 sec
Stored particles ~ 10^8



Is all this useful for something?



During the last decade, the global positioning system (GPS) has become almost a household item. Due to the altitude and speed of the GPS satellites, general and special relativity have to be taken into account. Otherwise, position readout errors of up to 1 km would accumulate during a day (bad for yachting and smart bombs)!

Test theories of special relativity

Test theory: general theoretical framework, reduces to special relativity (SR) for a particular choice of the functions.

Mansouri & Sexl [Gen.Rel. & Gravit. 8, 497 (1977)]:

- preferred system Σ, speed of light c_0 is assumed constant and isotropic in this frame only
- laboratory system S, moving with velocity w w.r.t. Σ. Σ e.g. 3K microwave background, $w \approx \frac{300 \text{ km/sec}}{c}$