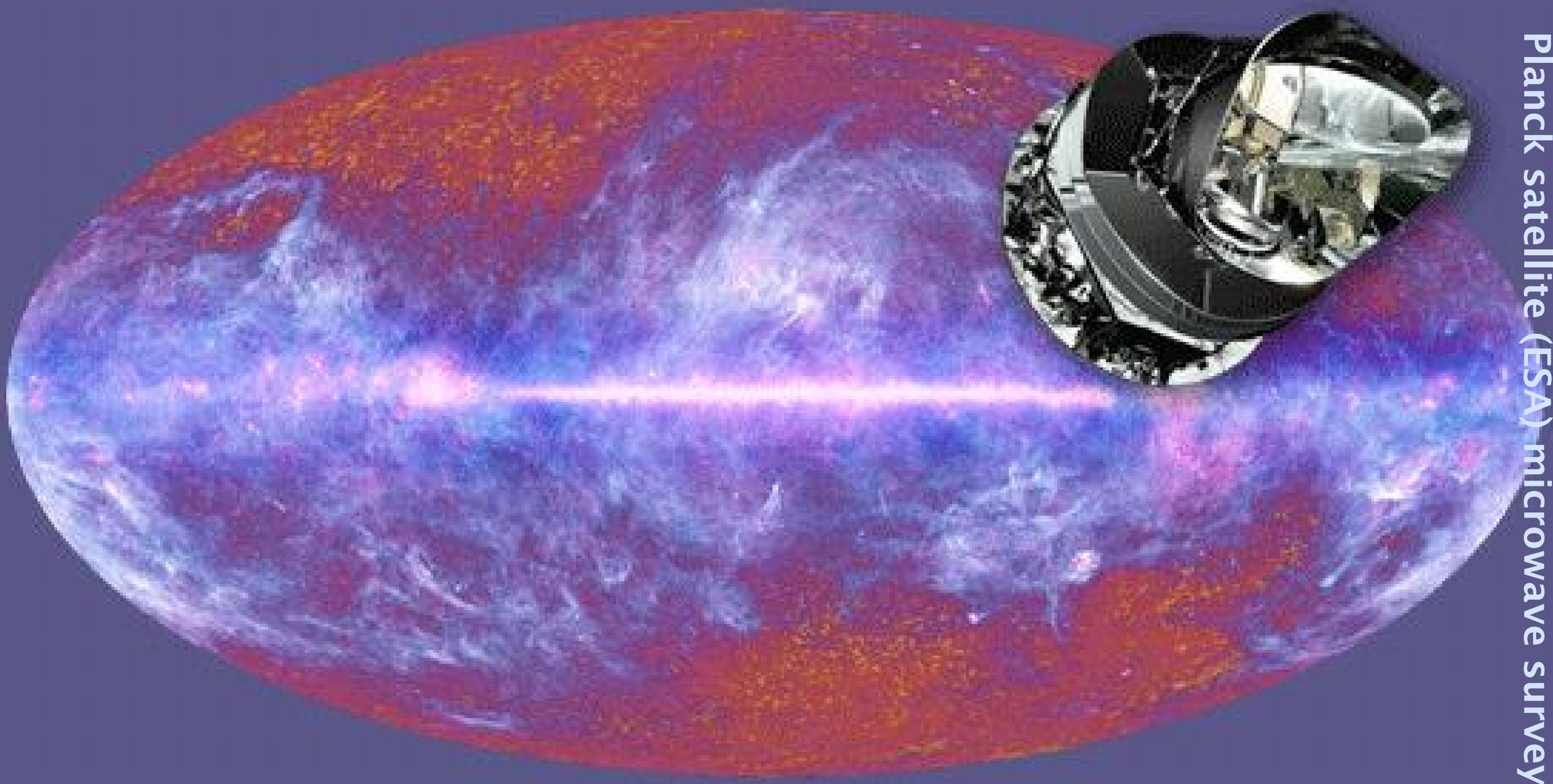
Testing Einstein's special relativity with clocks moving near the speed of light

Making our way (really slowly) to the Planck scale

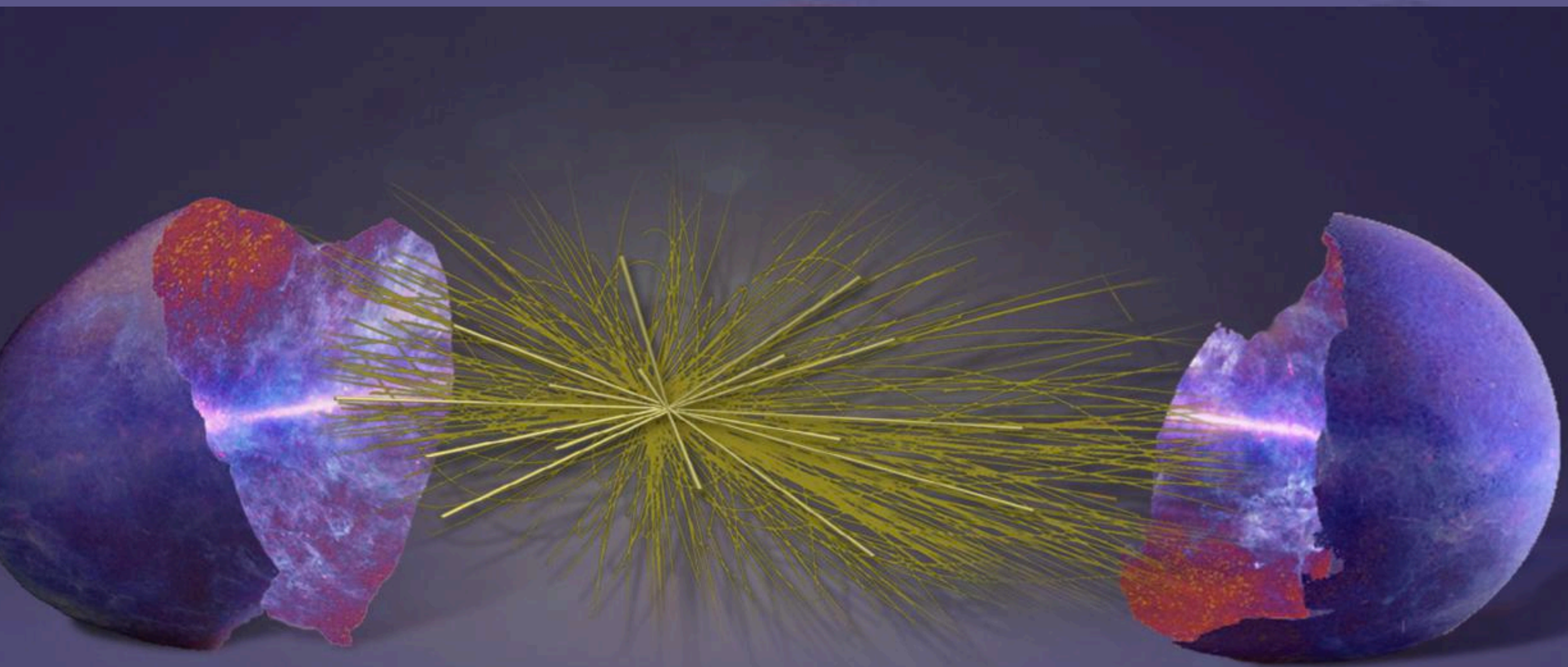
G. Gwinner
University of Manitoba

The very smallest and the very largest: From the Planck scale to the cosmos



Planck satellite (ESA) microwave survey

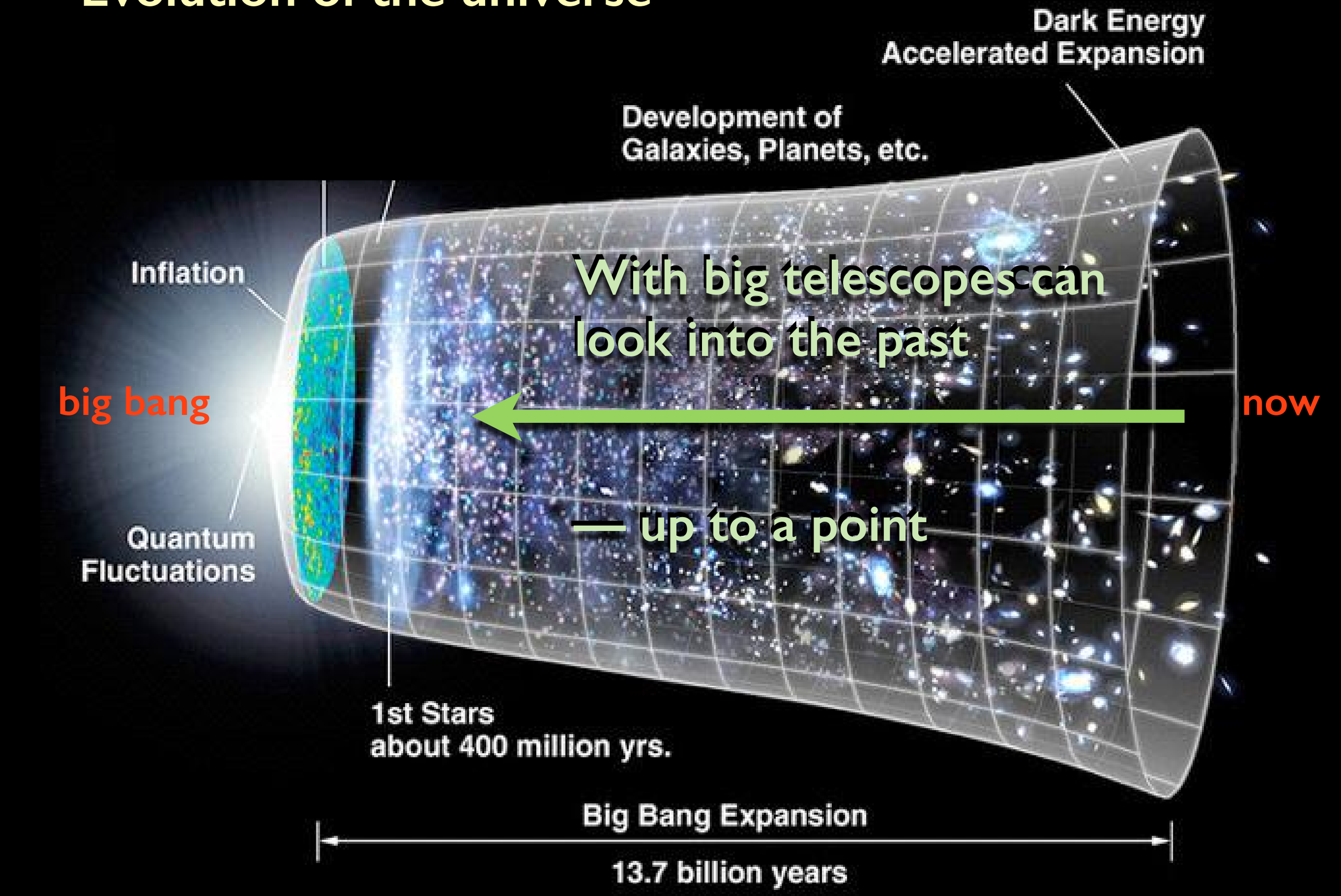
The very smallest and the very largest: From the Planck scale to the cosmos



PASCOS 2011 conference poster

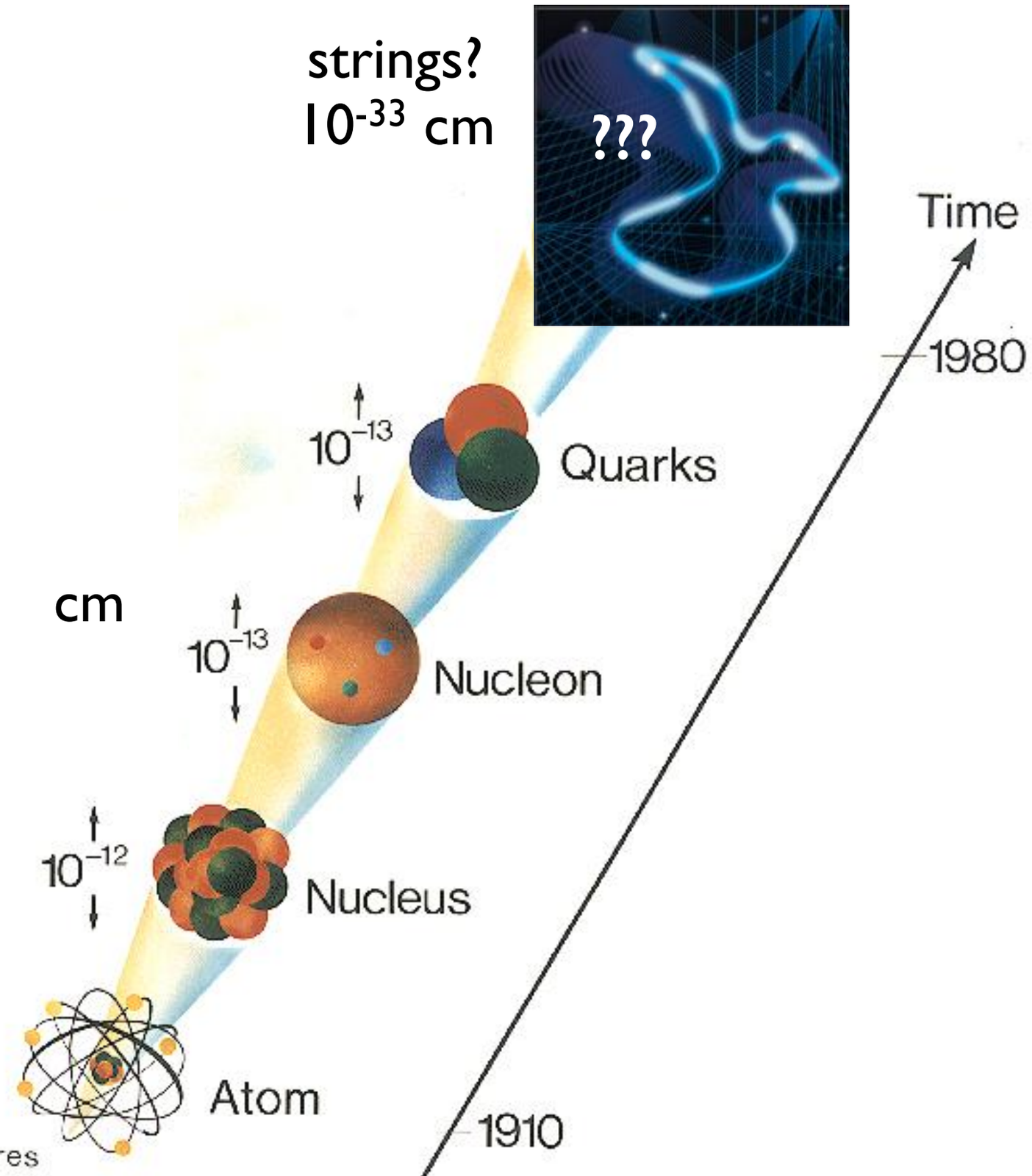
Cosmology and particle physics increasingly connected

Evolution of the universe



http://discoverycenter.dk/content/cosmology-and-astro-particle-physics

To understand the large, we must understand the small — but how small ?



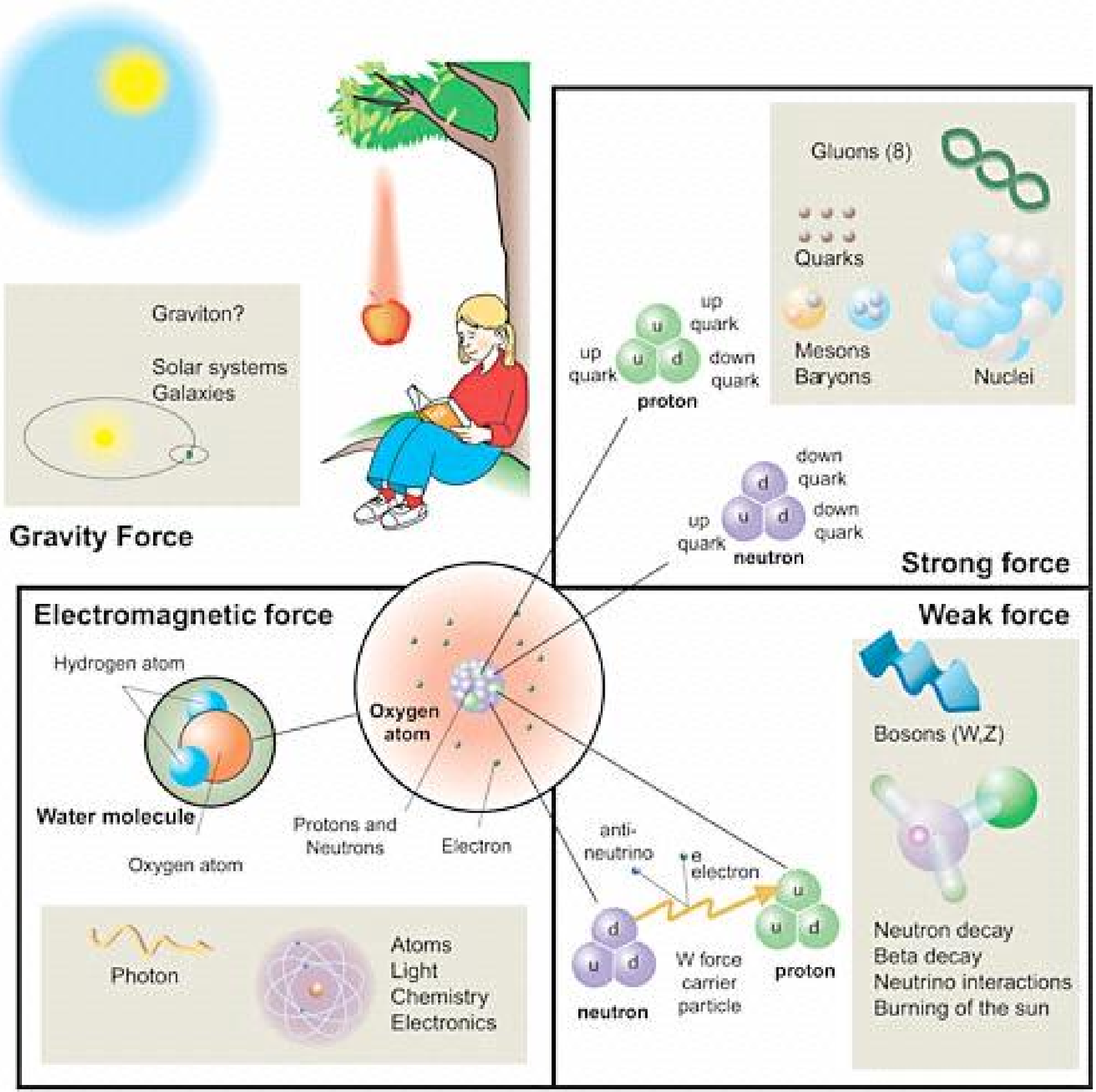
How do we probe smaller and smaller distances?

Heisenberg uncertainty principle:

$$\Delta x \approx h/\Delta p$$

Need larger and larger momenta (and energy)

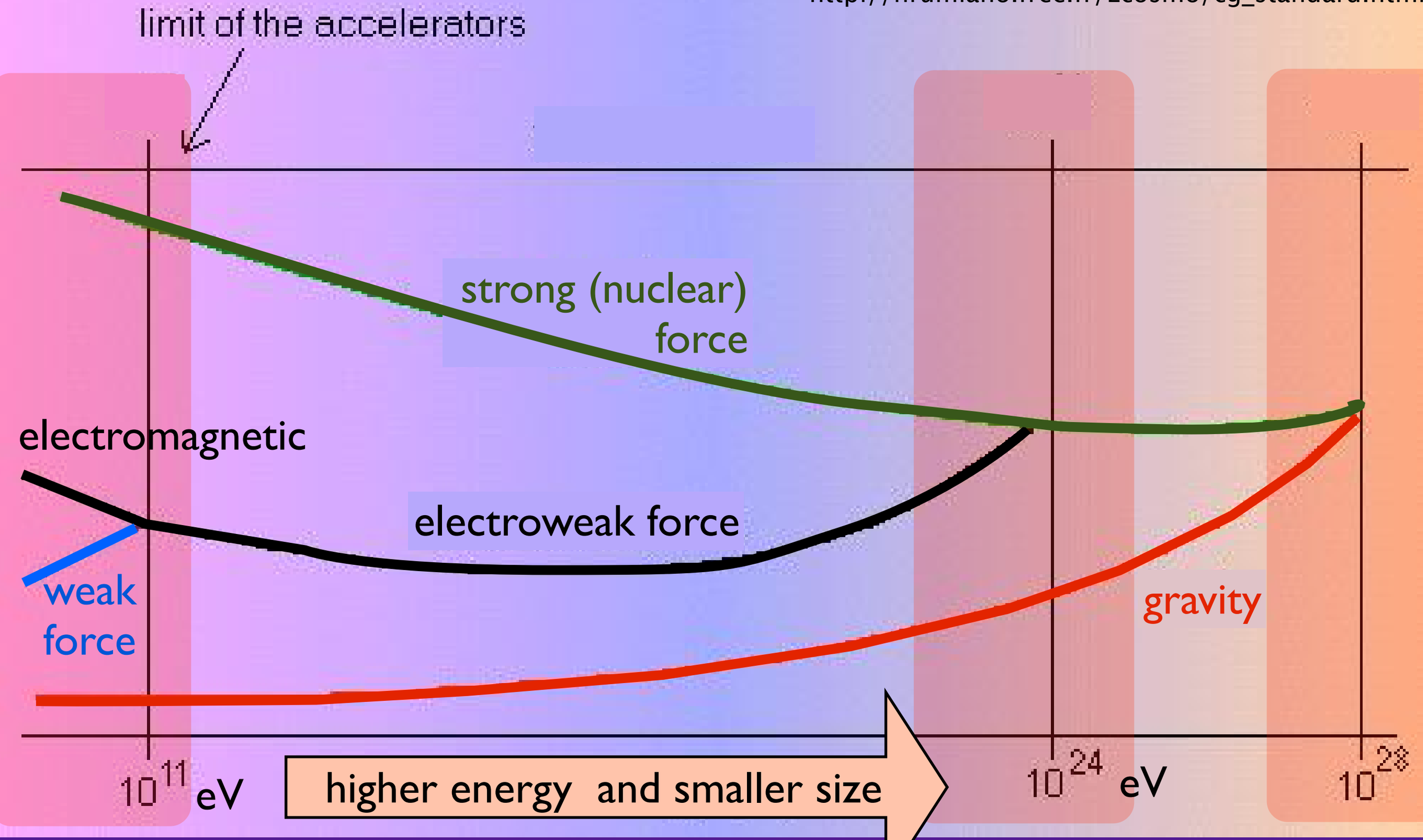
The fundamental forces of nature



http://e-ducation.net/images/phypub1lowen.jpg

They have very different strength — and it changes !

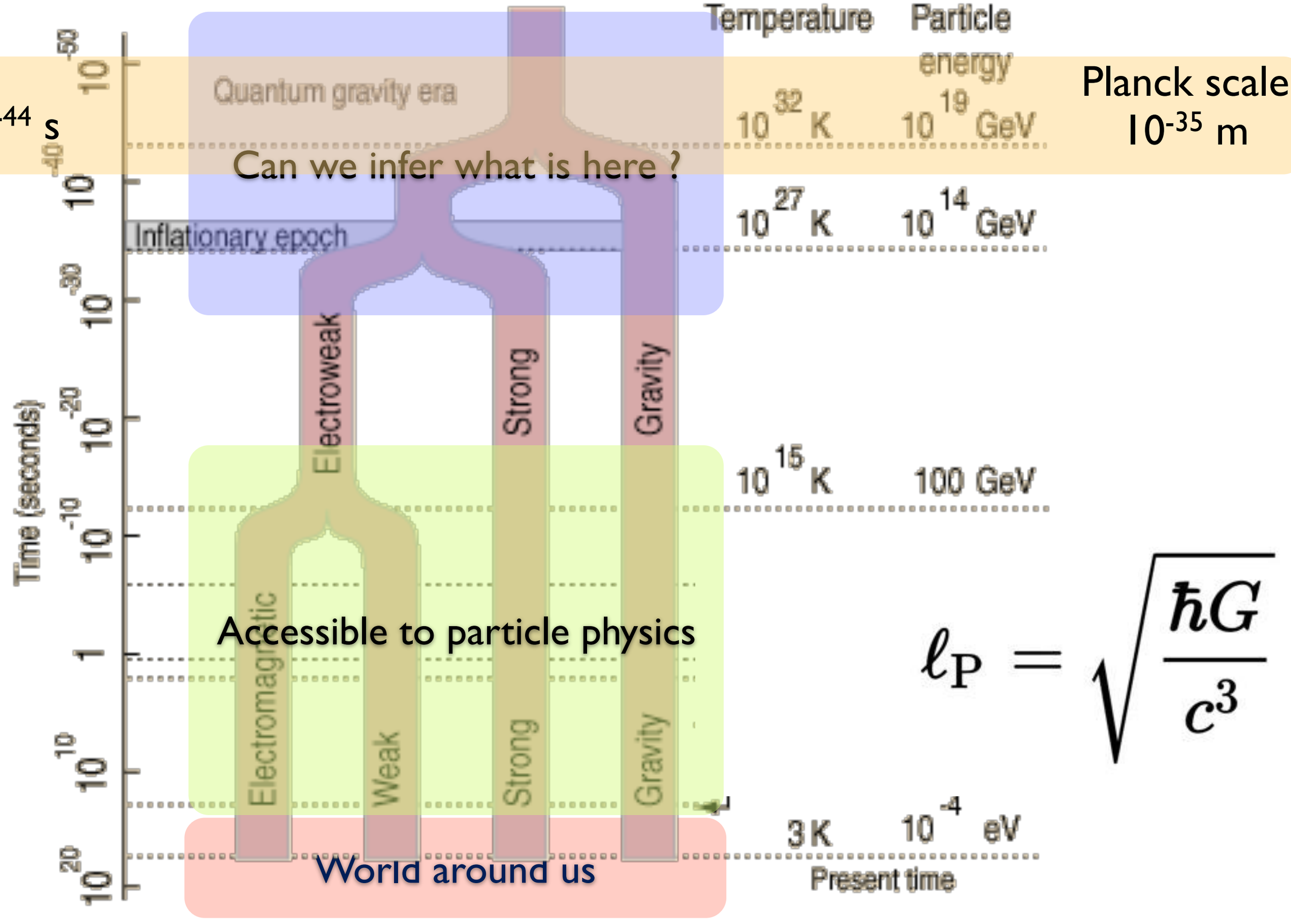
http://nrumiano.free.fr/Ecosmo/cg_standard.html



Standard Model

Grand Unification

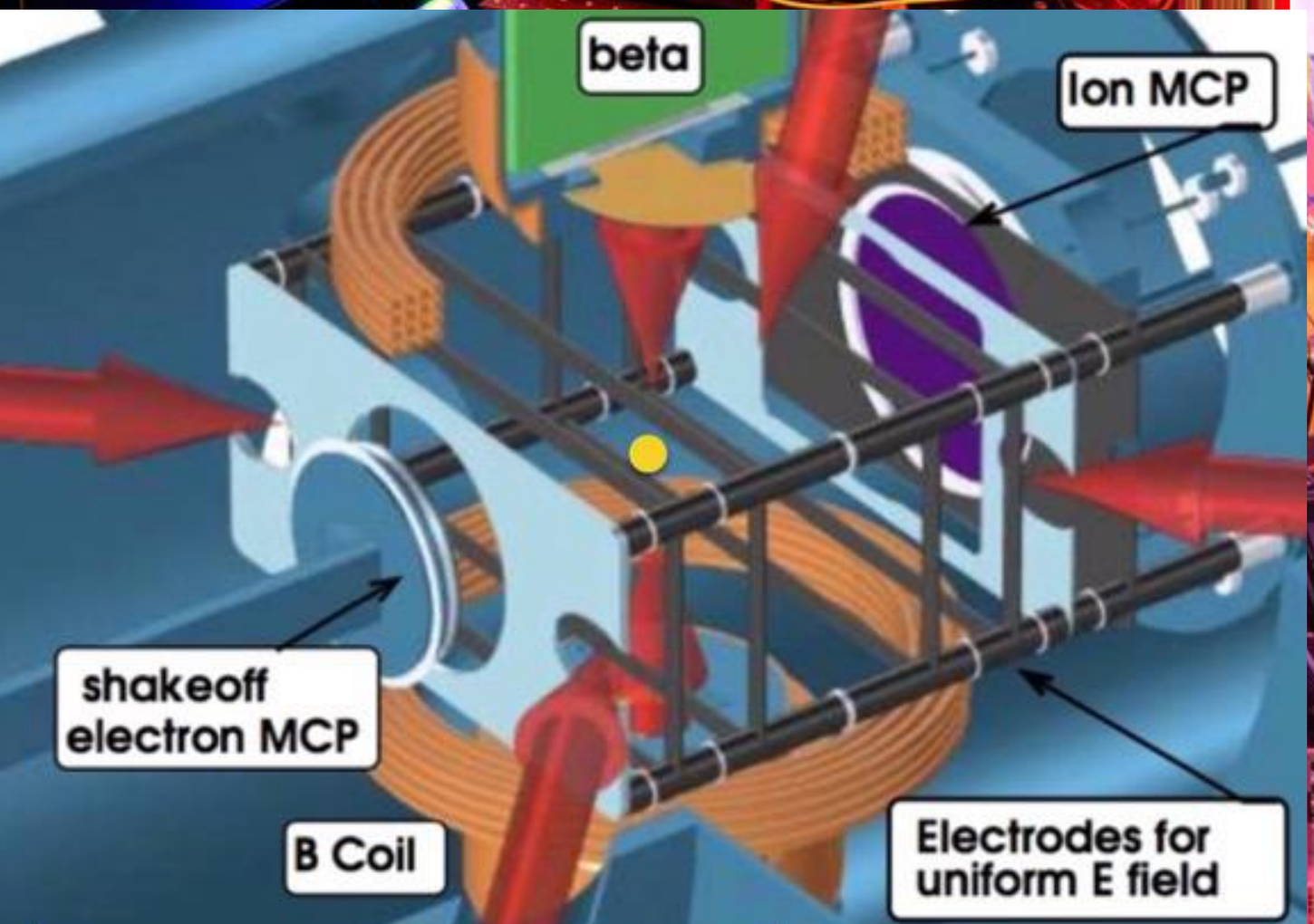
Theory of Everything

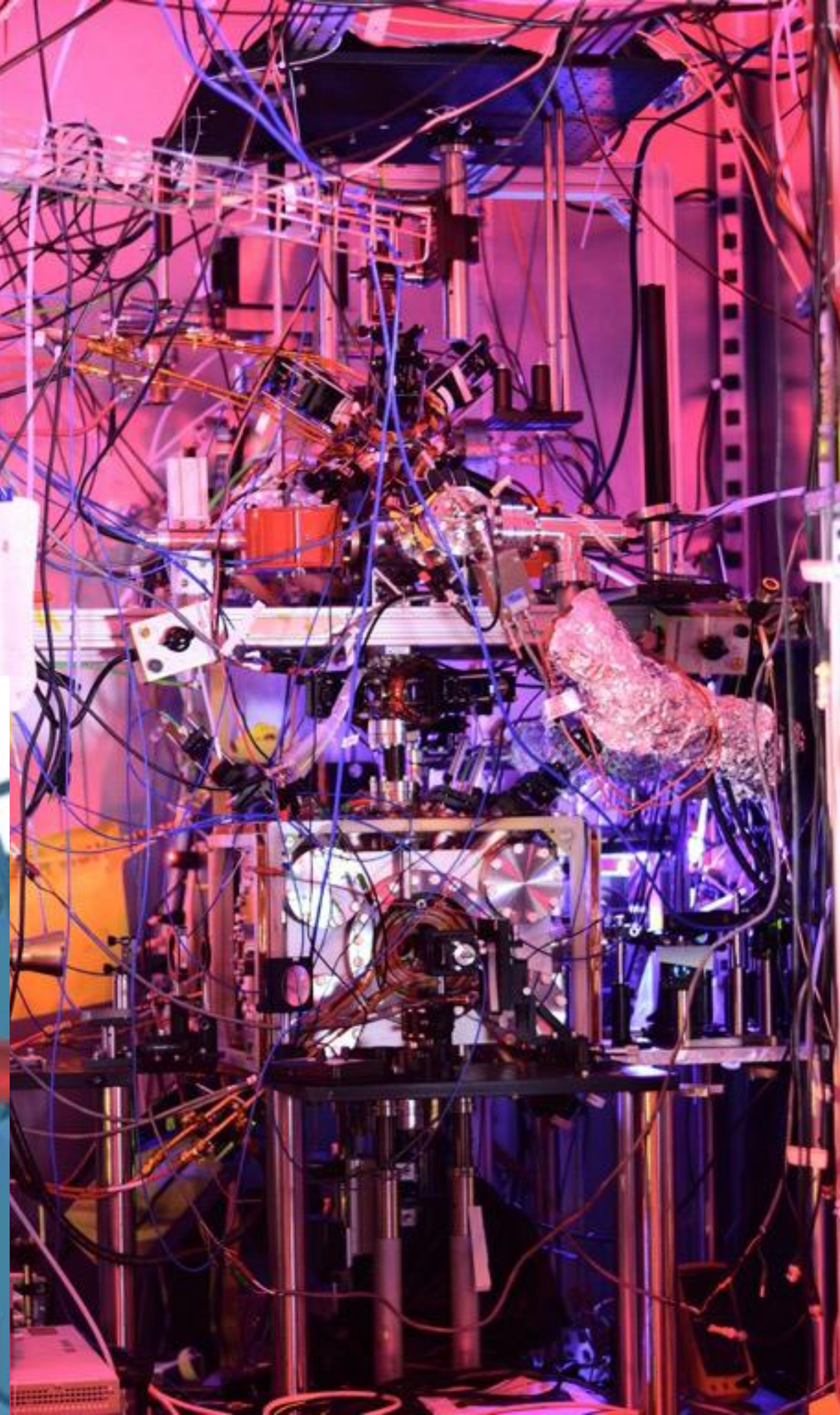

Temperature
Particle energy
Quantum gravity era
10^{32} K
10^{19} GeV
Inflationary epoch
10^{27} K
10^{14} GeV
Electroweak
Strong
Gravity
10^{15} K
100 GeV
Time (seconds)
Electromagnetic
Weak
Strong
Gravity
3 K
10^{-4} eV
Present time
10^{-44} s
Planck scale
10^{-35} m
Can we infer what is here ?
Accessible to particle physics
World around us
$\ell_P = \sqrt{\frac{\hbar G}{c^3}}$

How can we probe the Planck scale without going there ?

- Planck scale physics has ramifications at lower energies
- Make very precise measurements a low energy and hope to find a glimpse

- The approach of our experiment:
  - All 4 fundamental forces (or interactions) are intimately connected to certain symmetries, and their violation can be probed


beta
Ion MCP
shakeoff
electron MCP
B Coil
Electrodes for
uniform E field



Violations of "Lorentz Symmetry"
The framework underlying Special Relativity

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

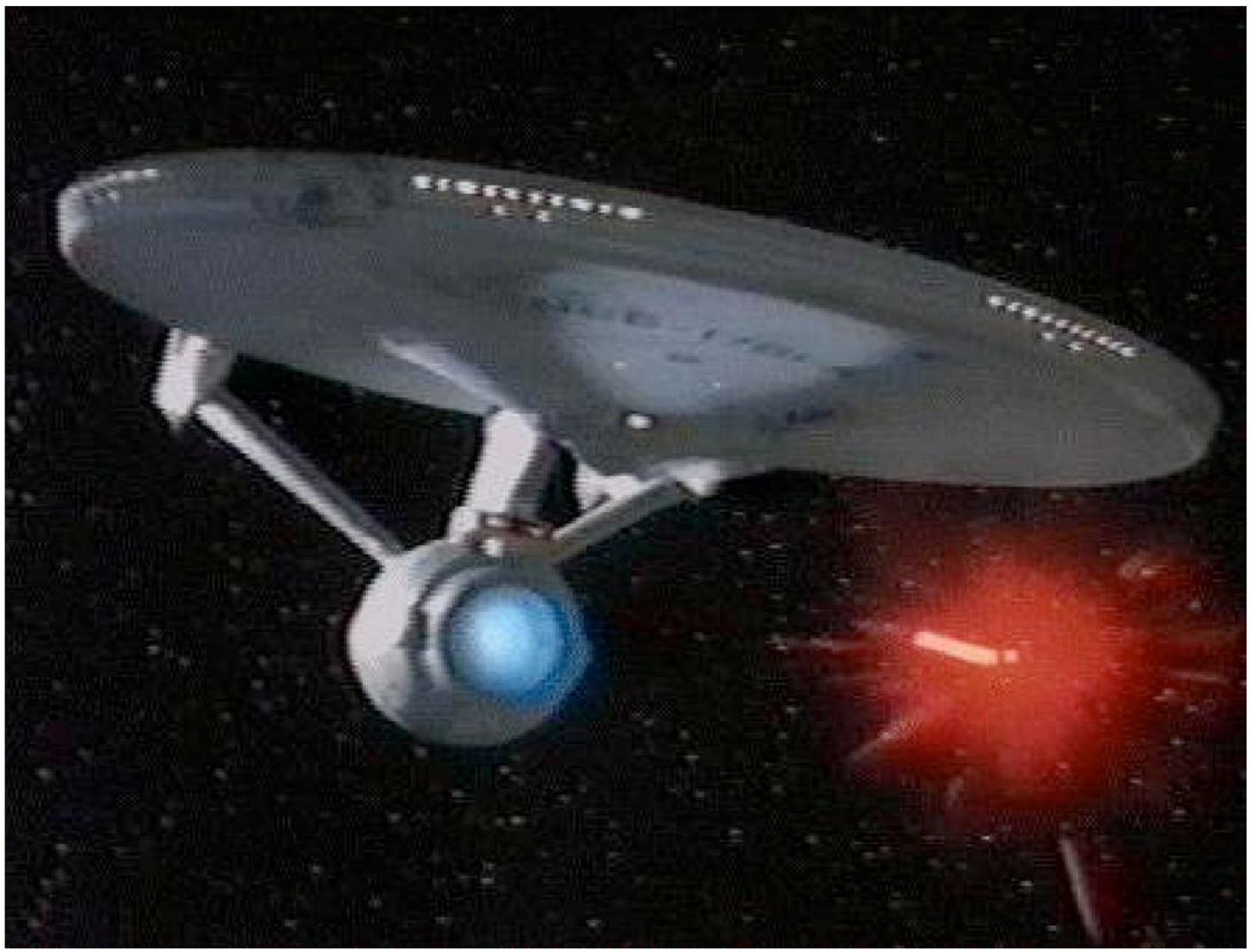
$v_{passenger} = 5$ km/h

$v_{total} = 205$ 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 ?

No, with
300 000 km/sec !

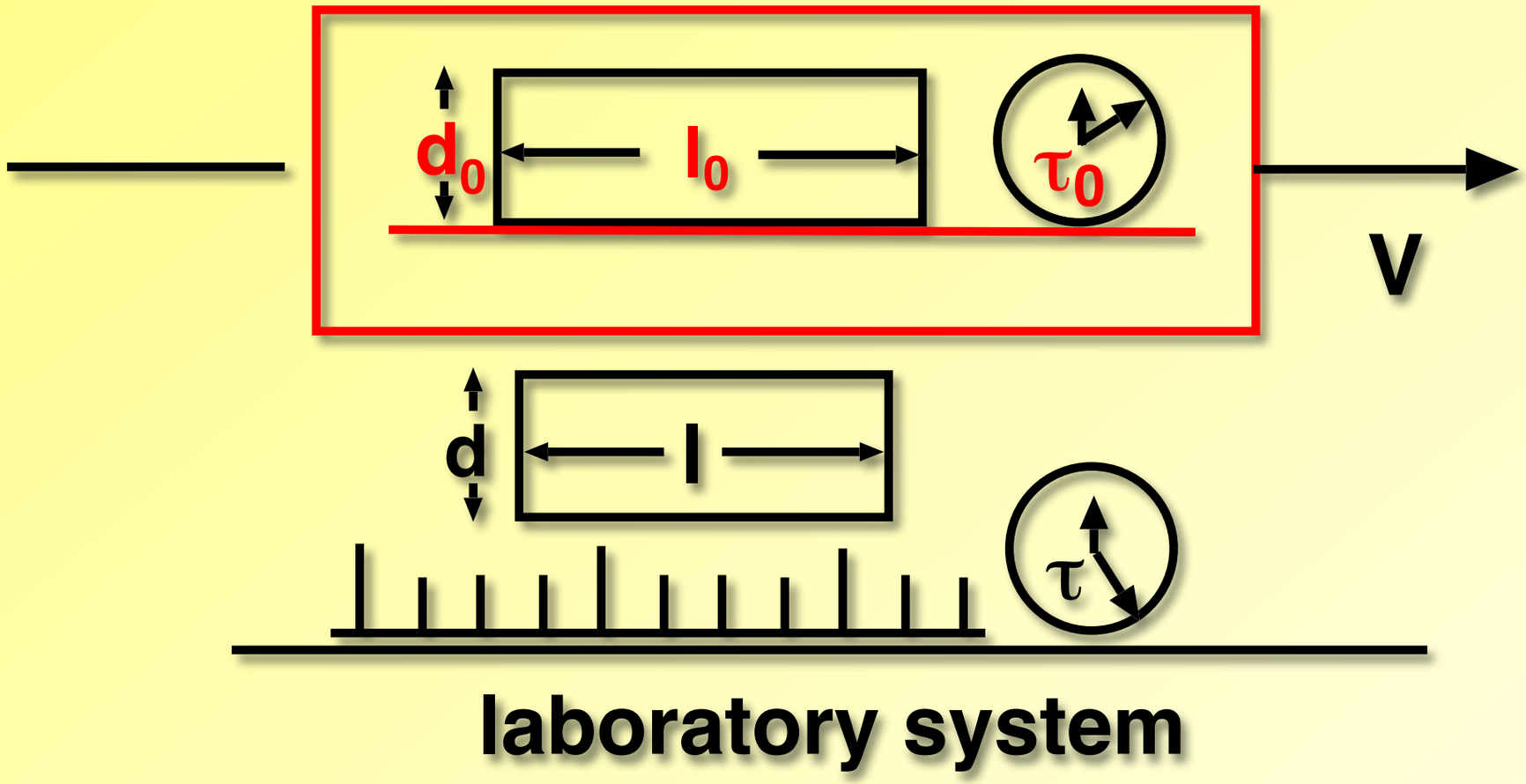
The central principle of the theory of special relativity (SR):

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

$$c = 299\,792.458 \text{ km/sec}$$

From this principle, alle laws of SR can be derived

Relativity on one slide



$l = l_0/\gamma$, $d = d_0$ $\quad \tau = \tau_0\gamma$ $\quad \gamma = \dfrac{1}{\sqrt{1 - (v/c)^2}}$

Lorentz contraction

time dilation

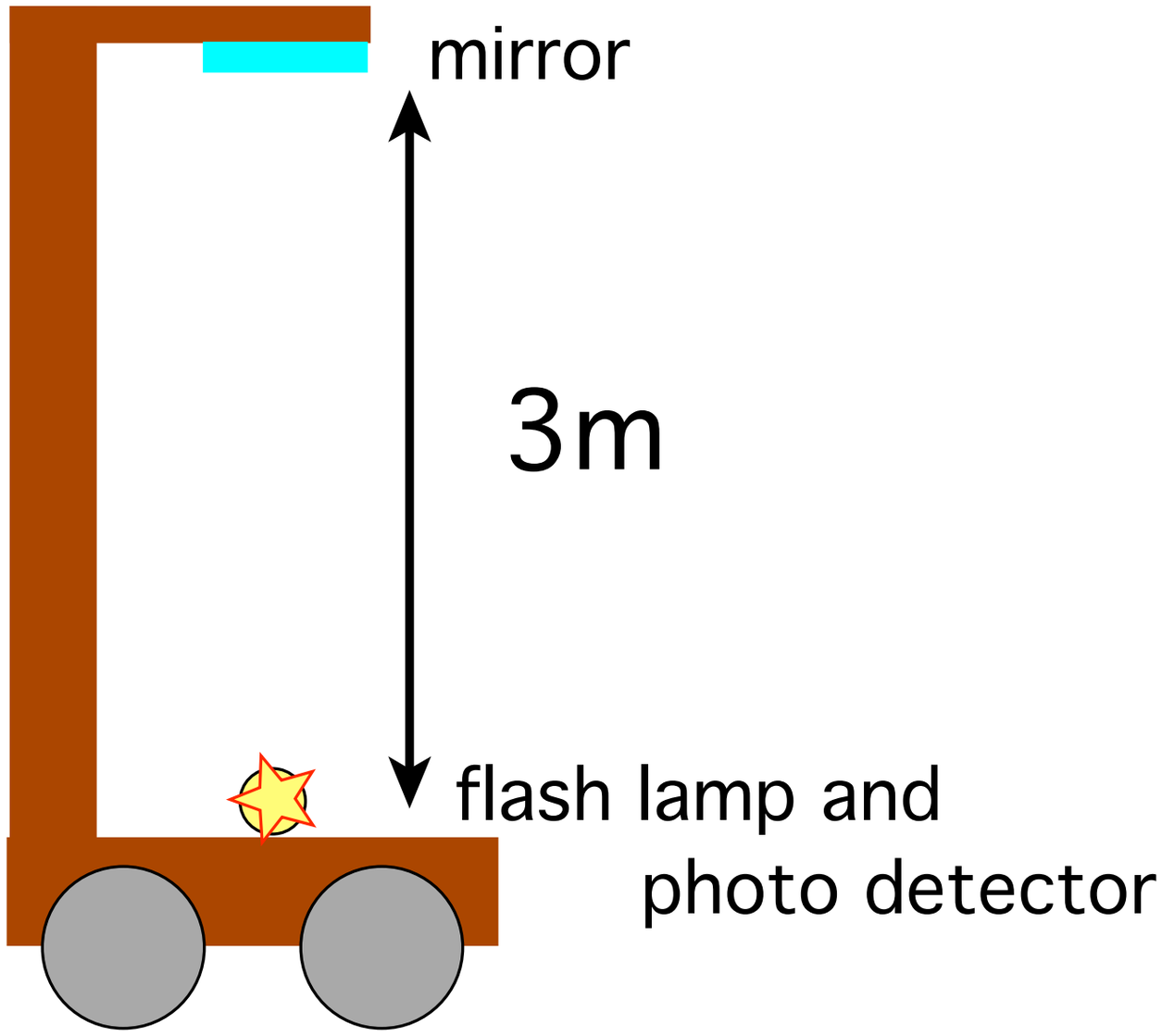
A fascinating manifestation of the theory of special relativity is the phenomenon of

time dilation

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

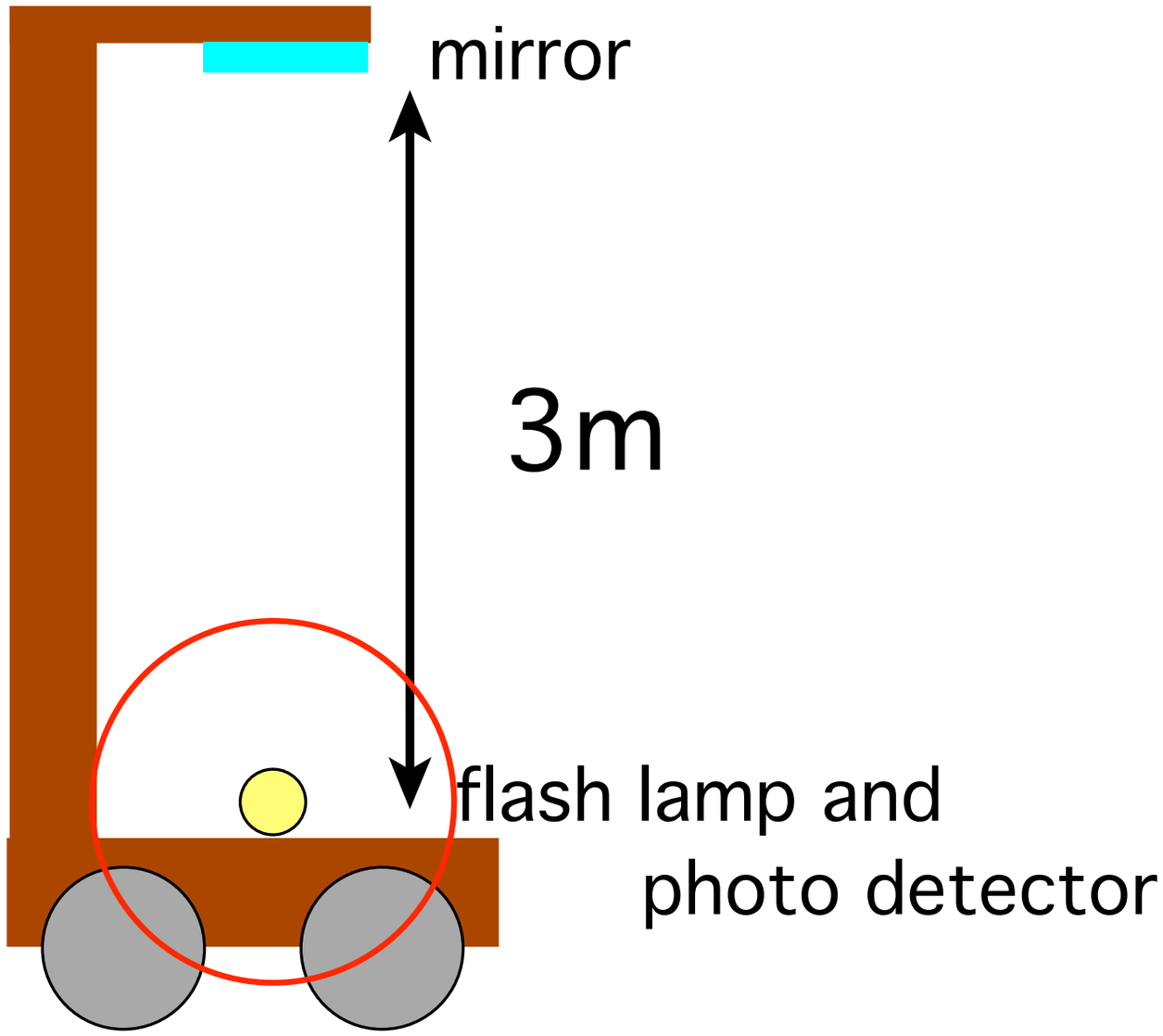
There is no absolute time!

t=0

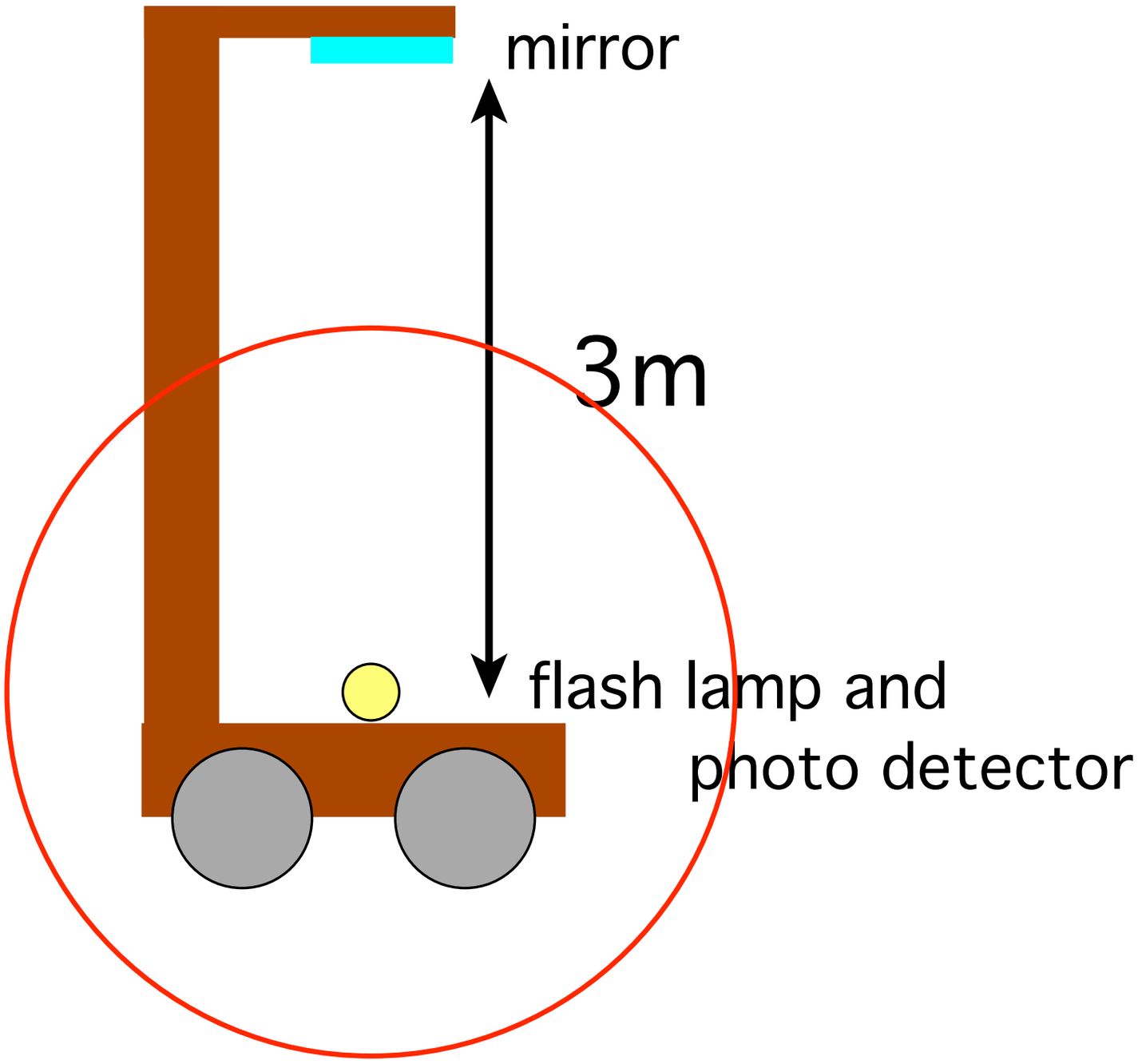


The round-trip time for light is the ‘tick’ of this clock

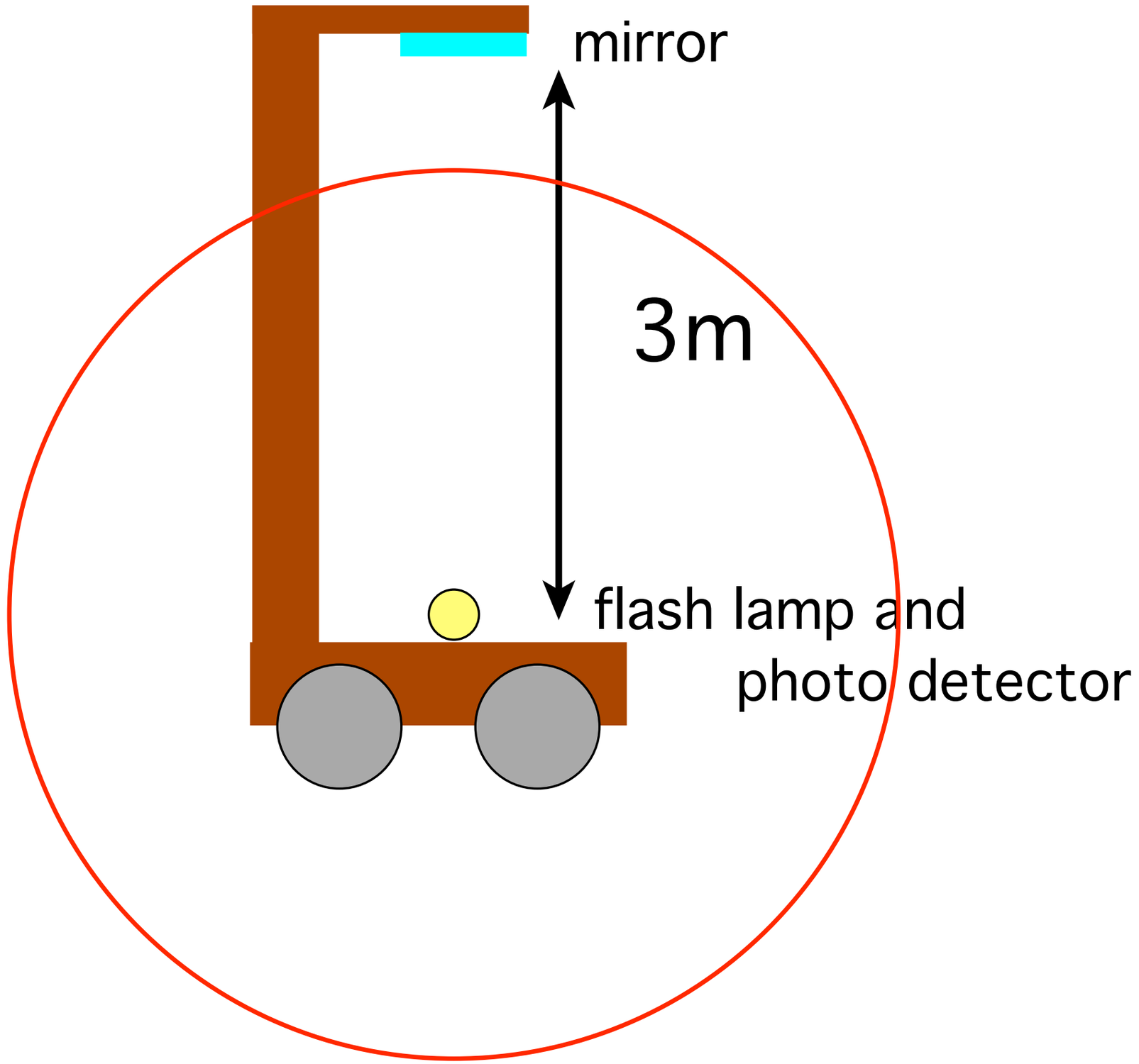
t=2.5 nsec



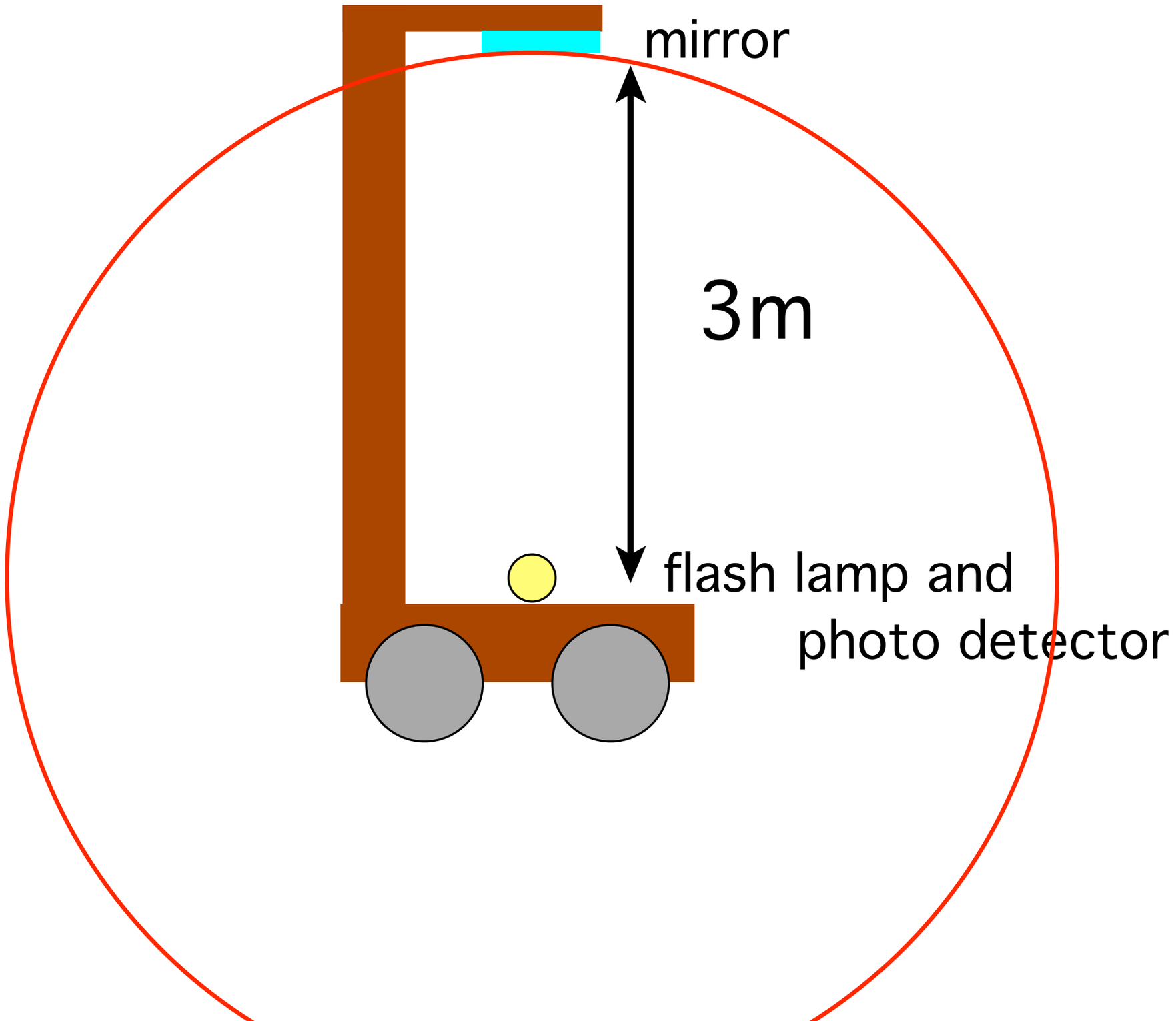
t=5.0 nsec



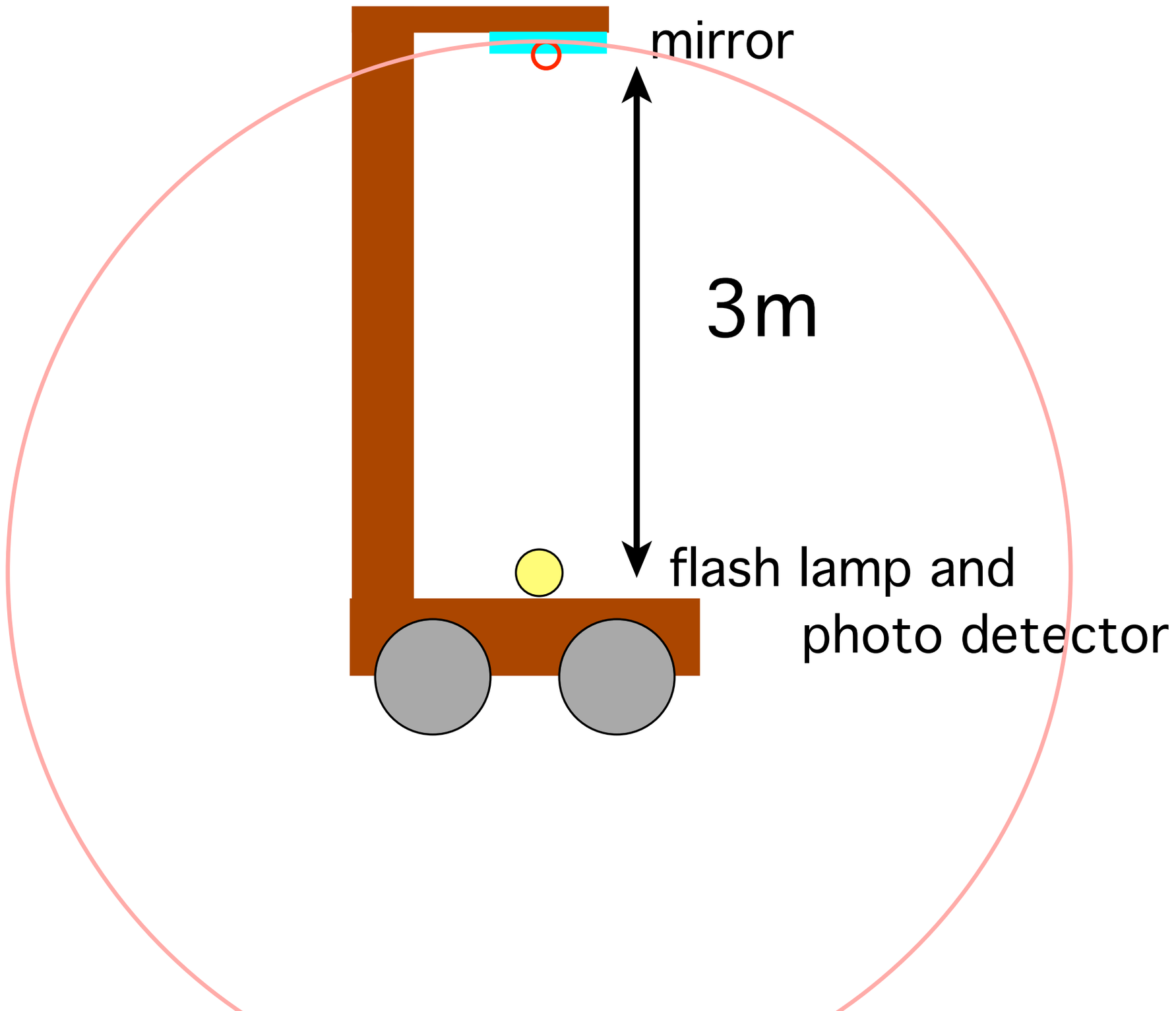
t=7.5 nsec



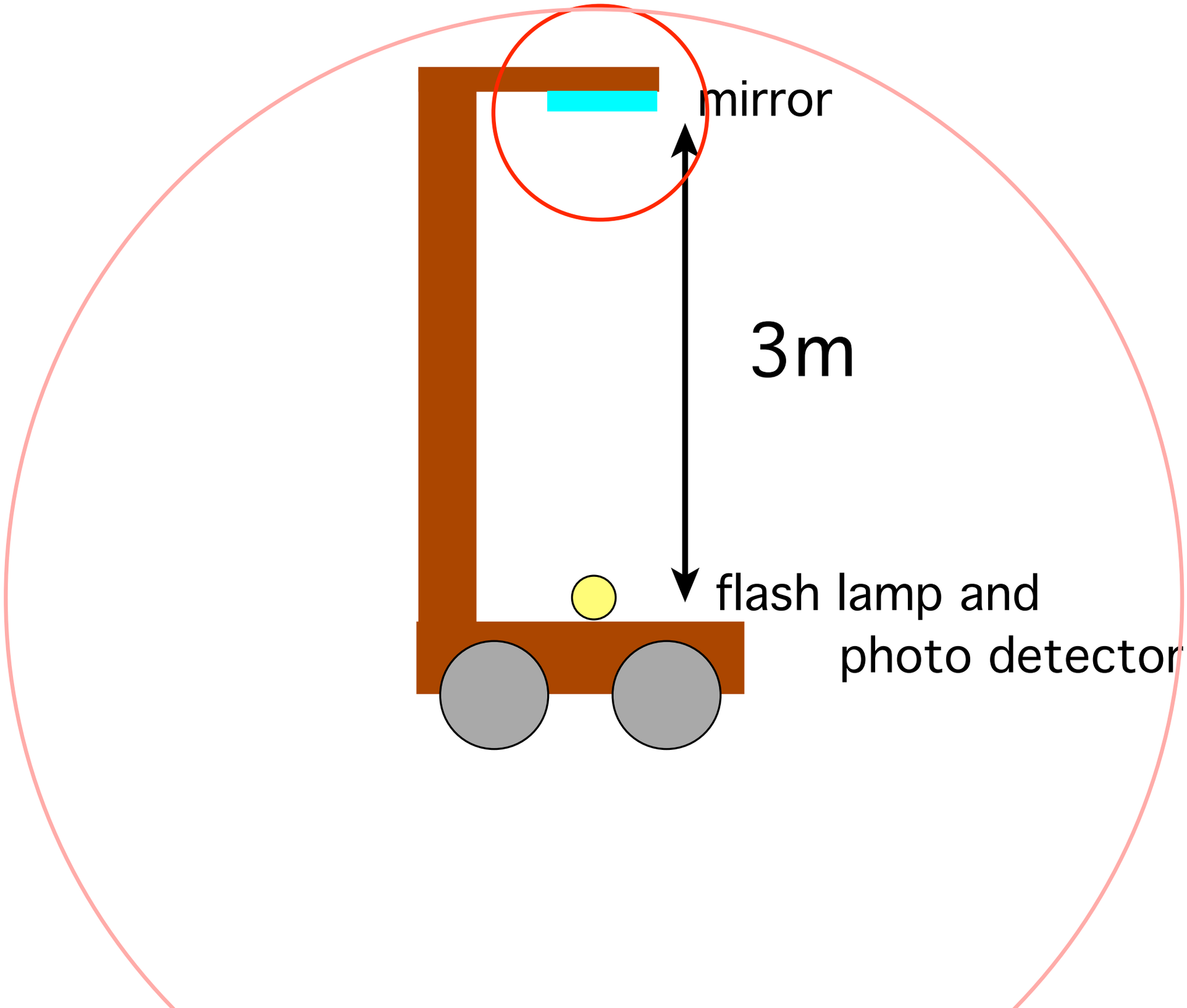
t=10.0 nsec



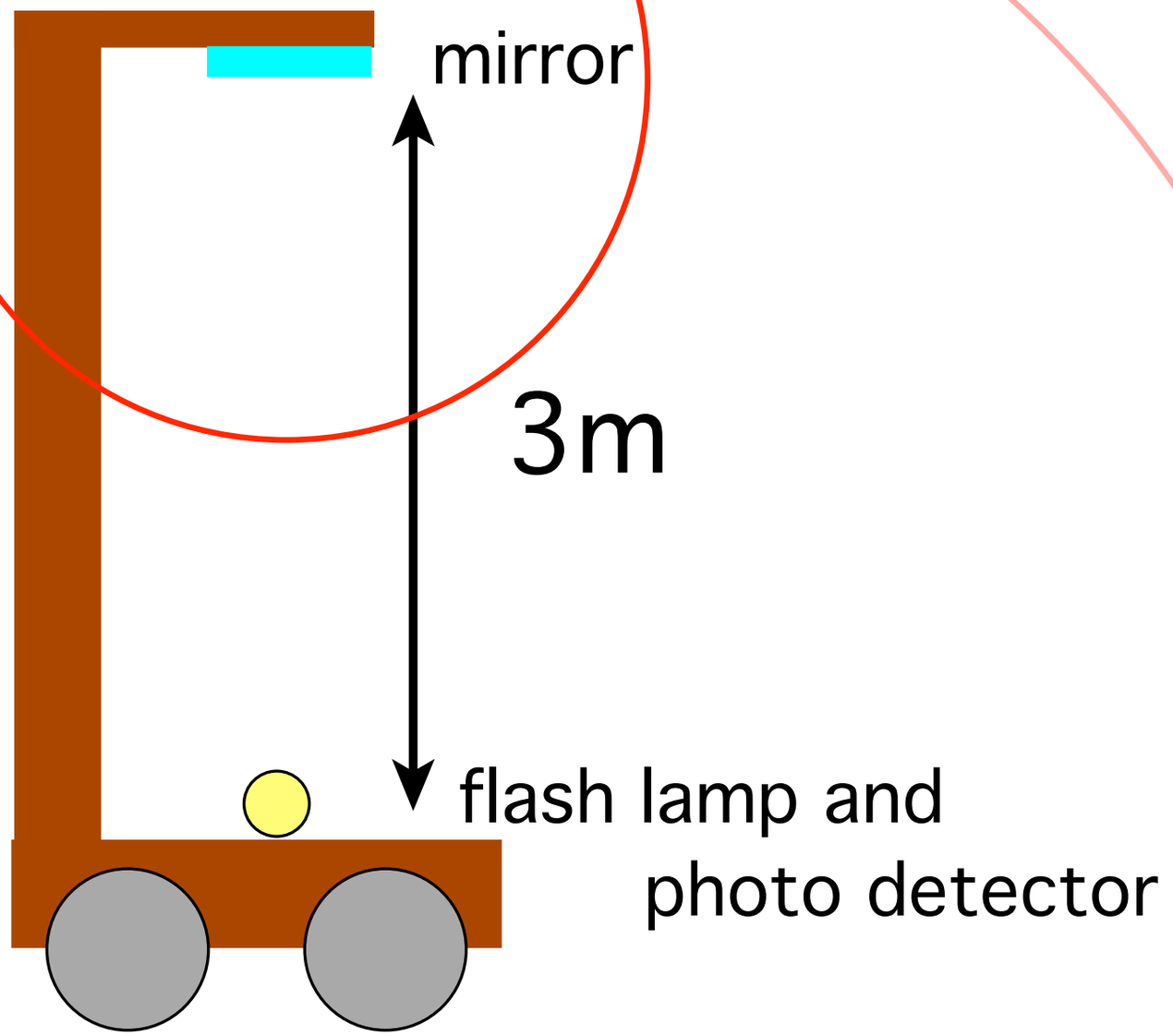
t=10.5 nsec



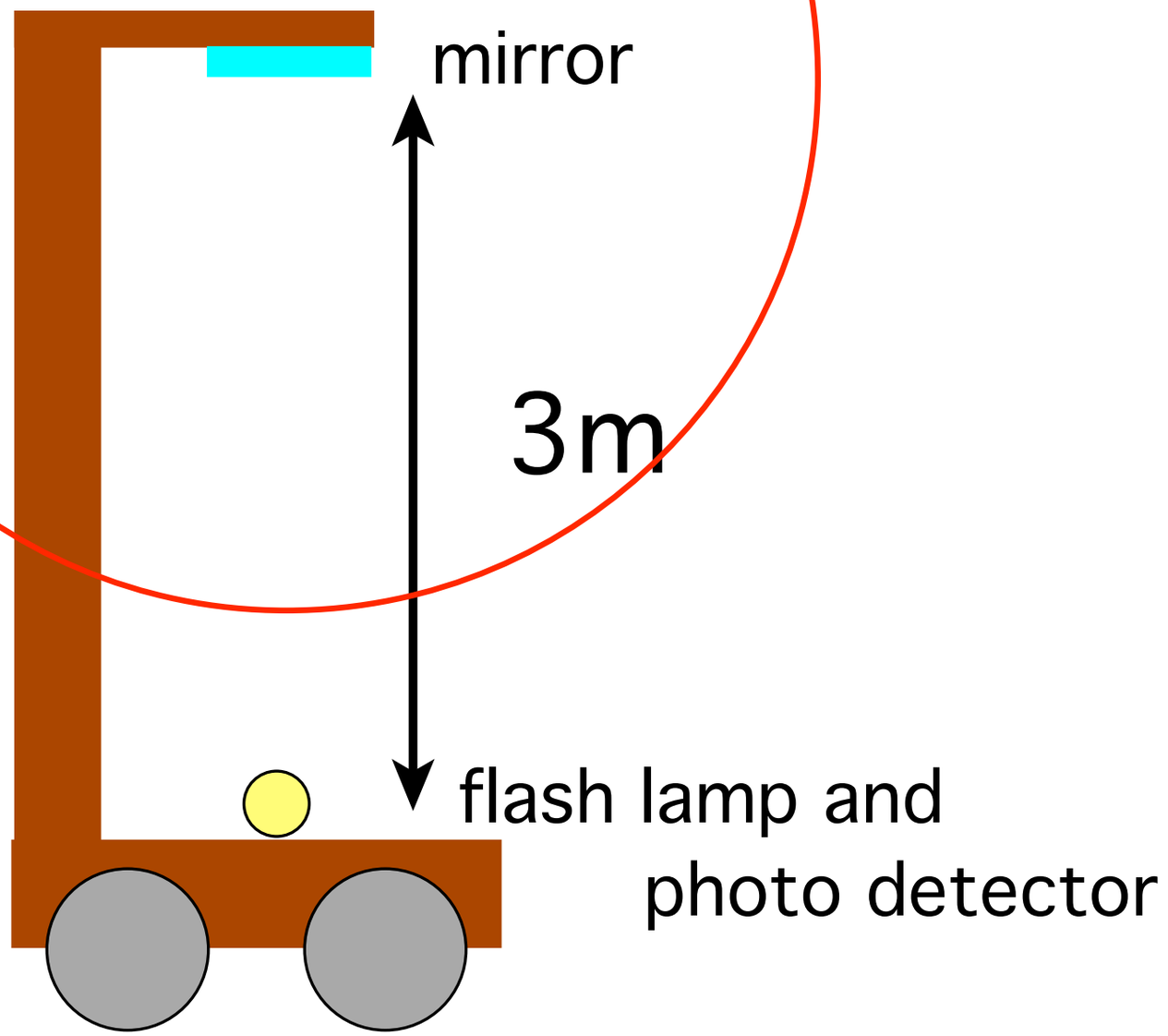
t=12.5 nsec



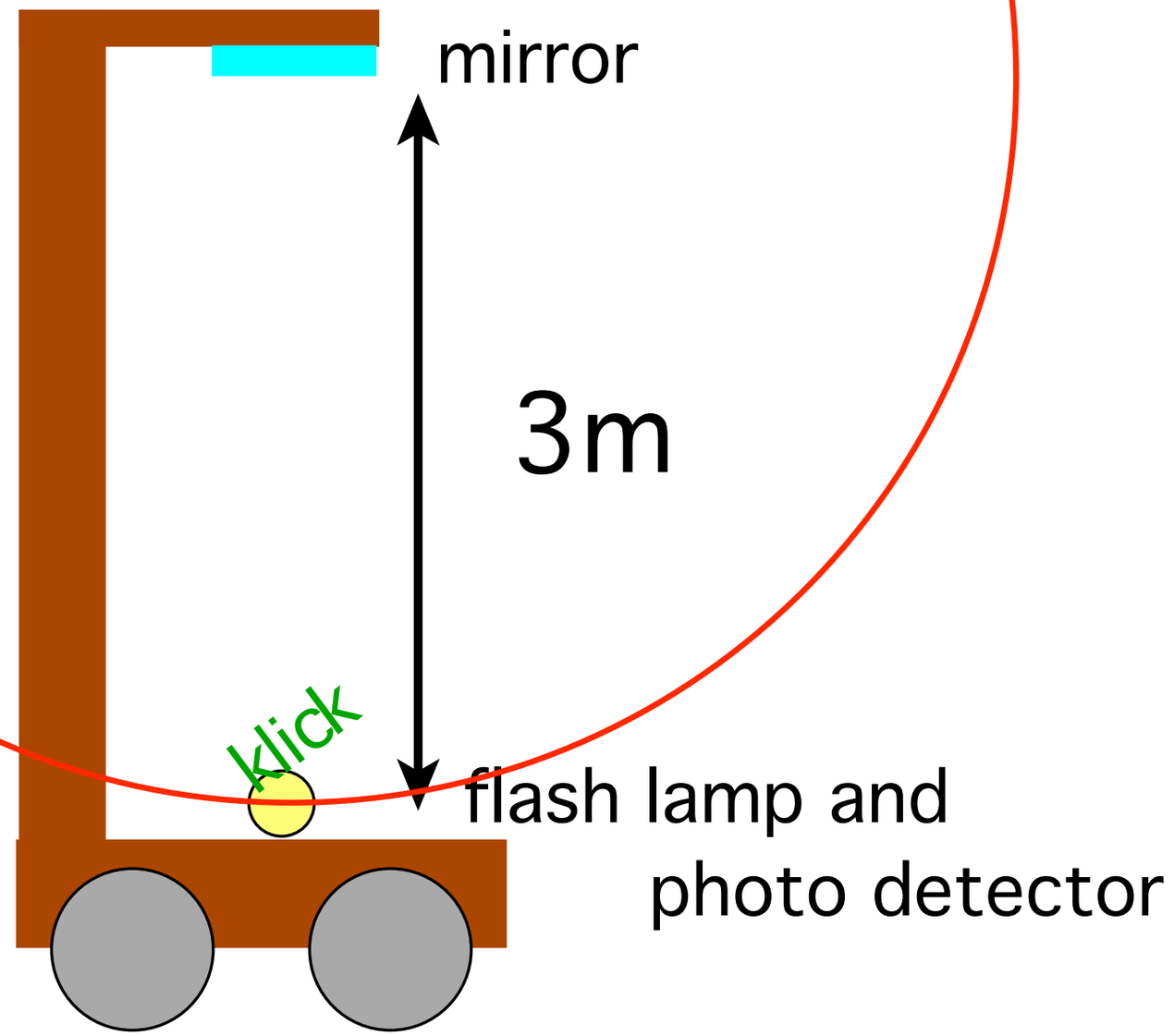
t=15.0 nsec

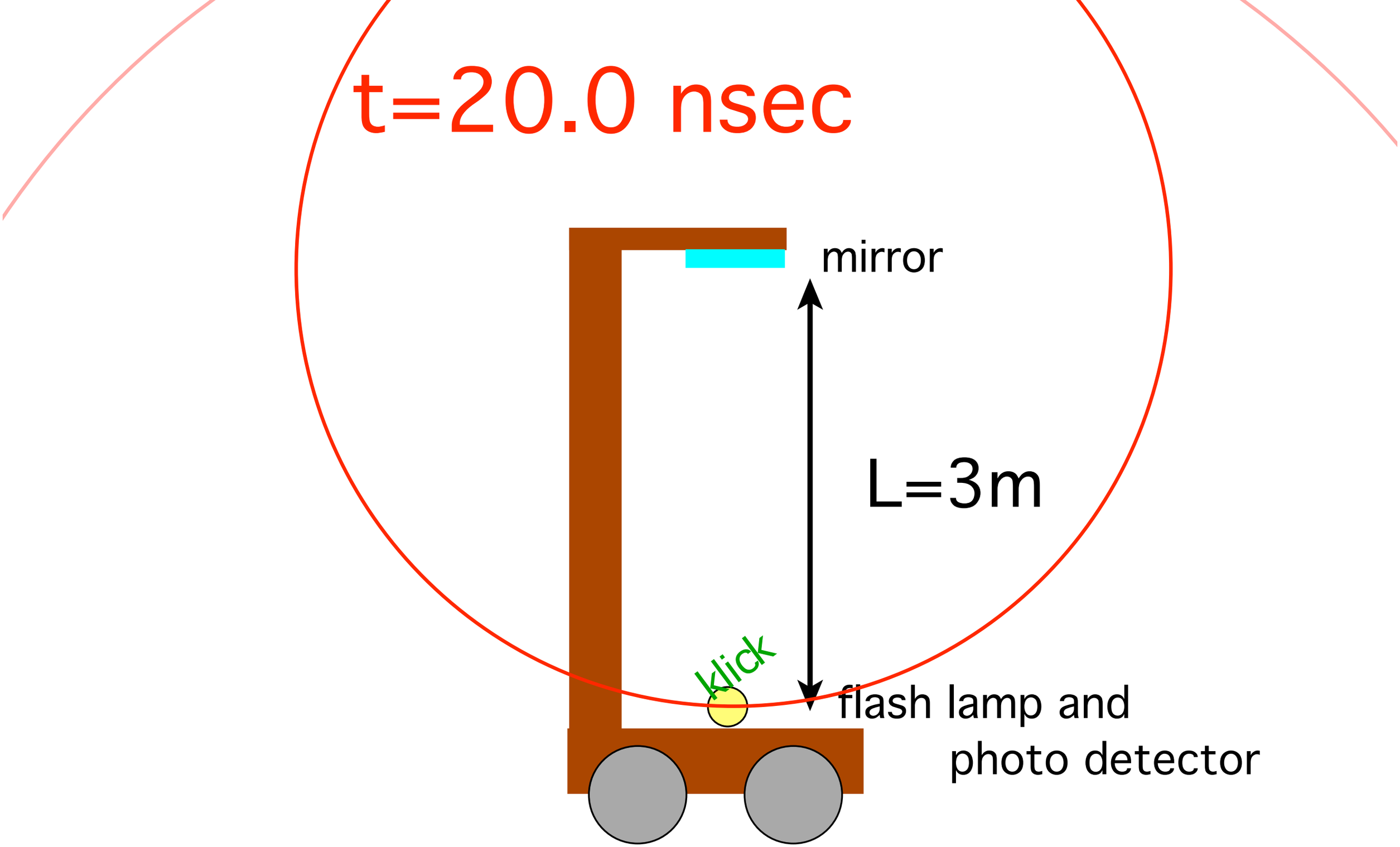


t=17.5 nsec



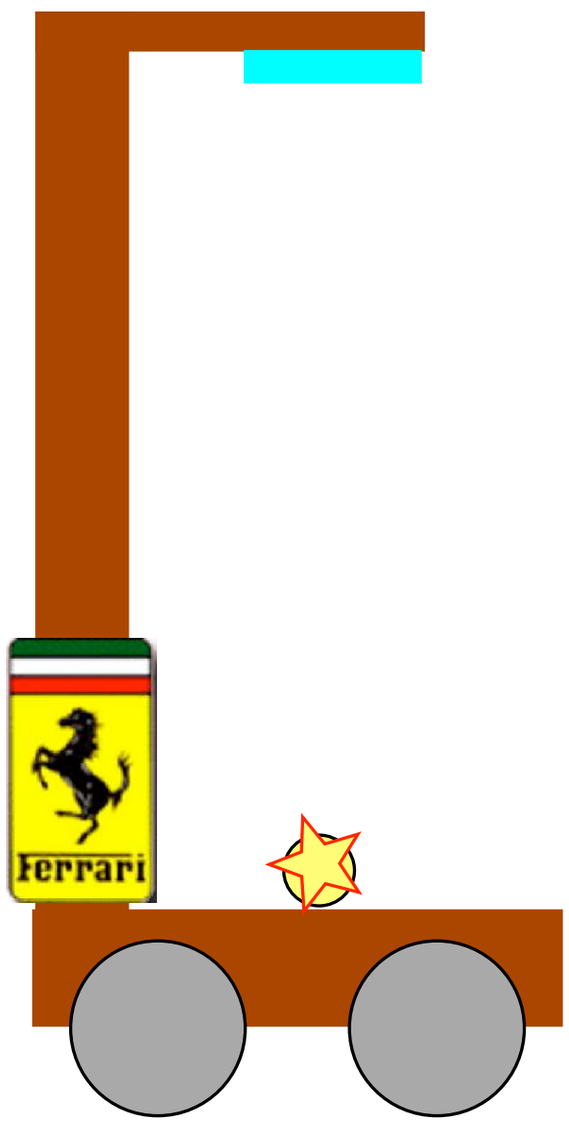
t=20.0 nsec





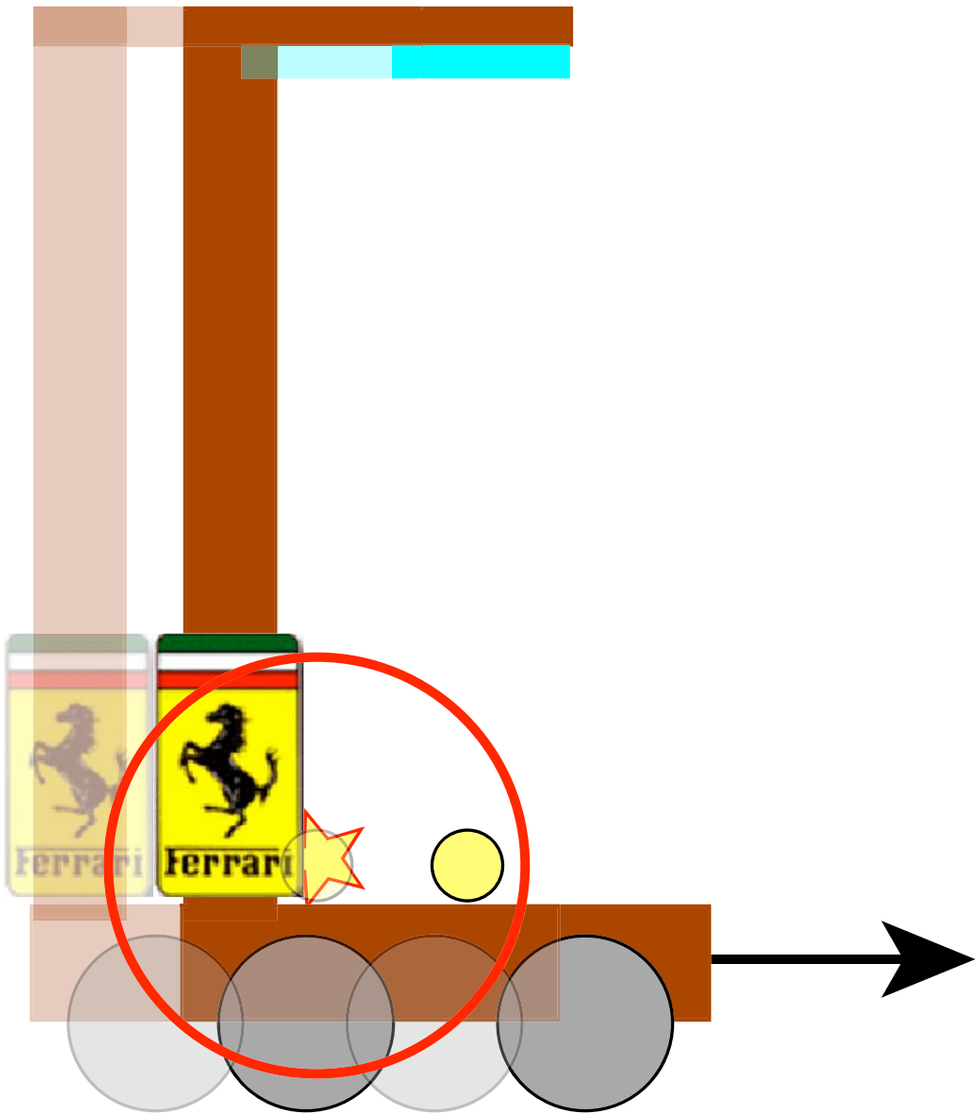
time from start (t=0) to the click (t_{click}): 2L/c

t=0

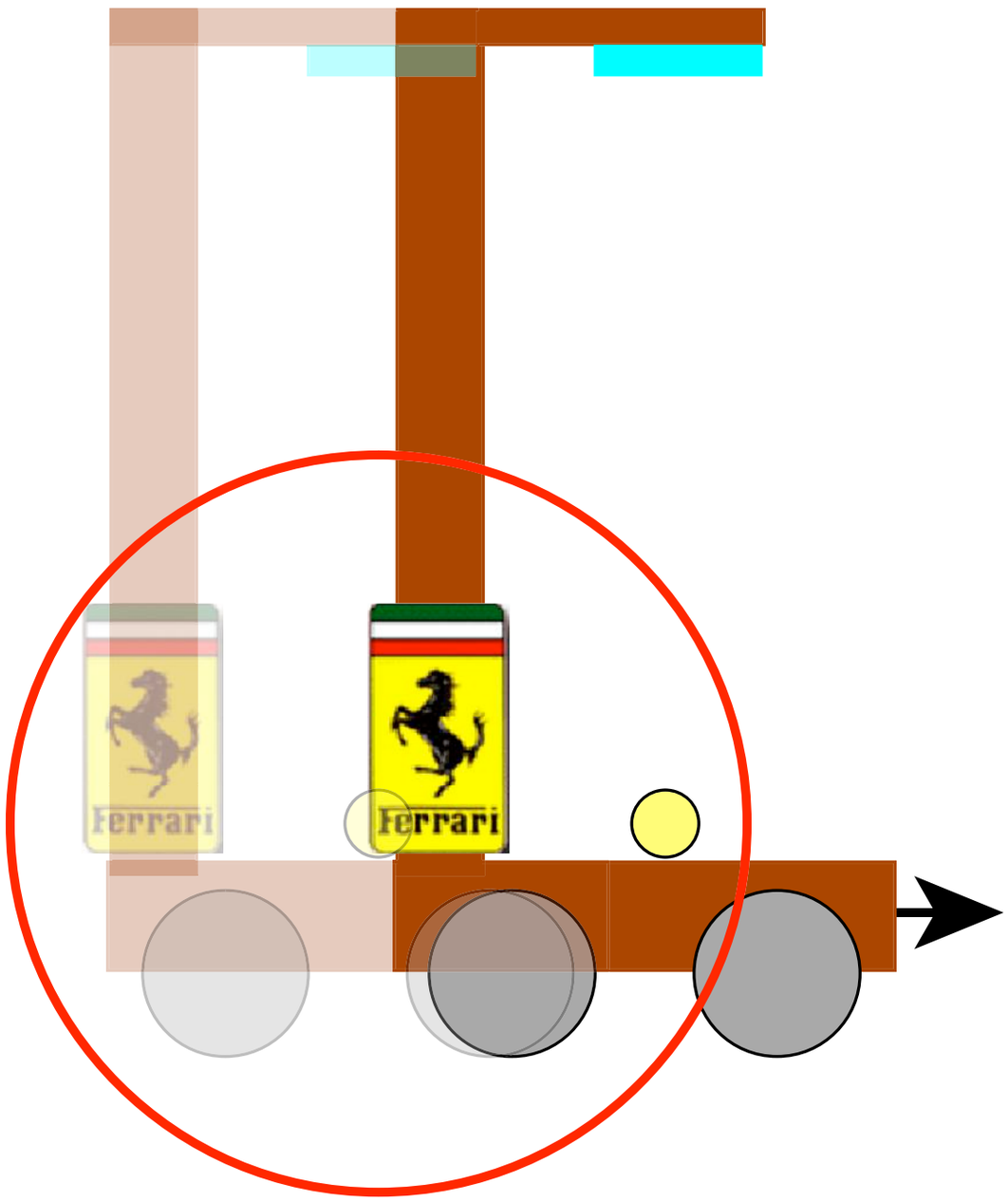


v=0.75 c
(225 000 km/sec)

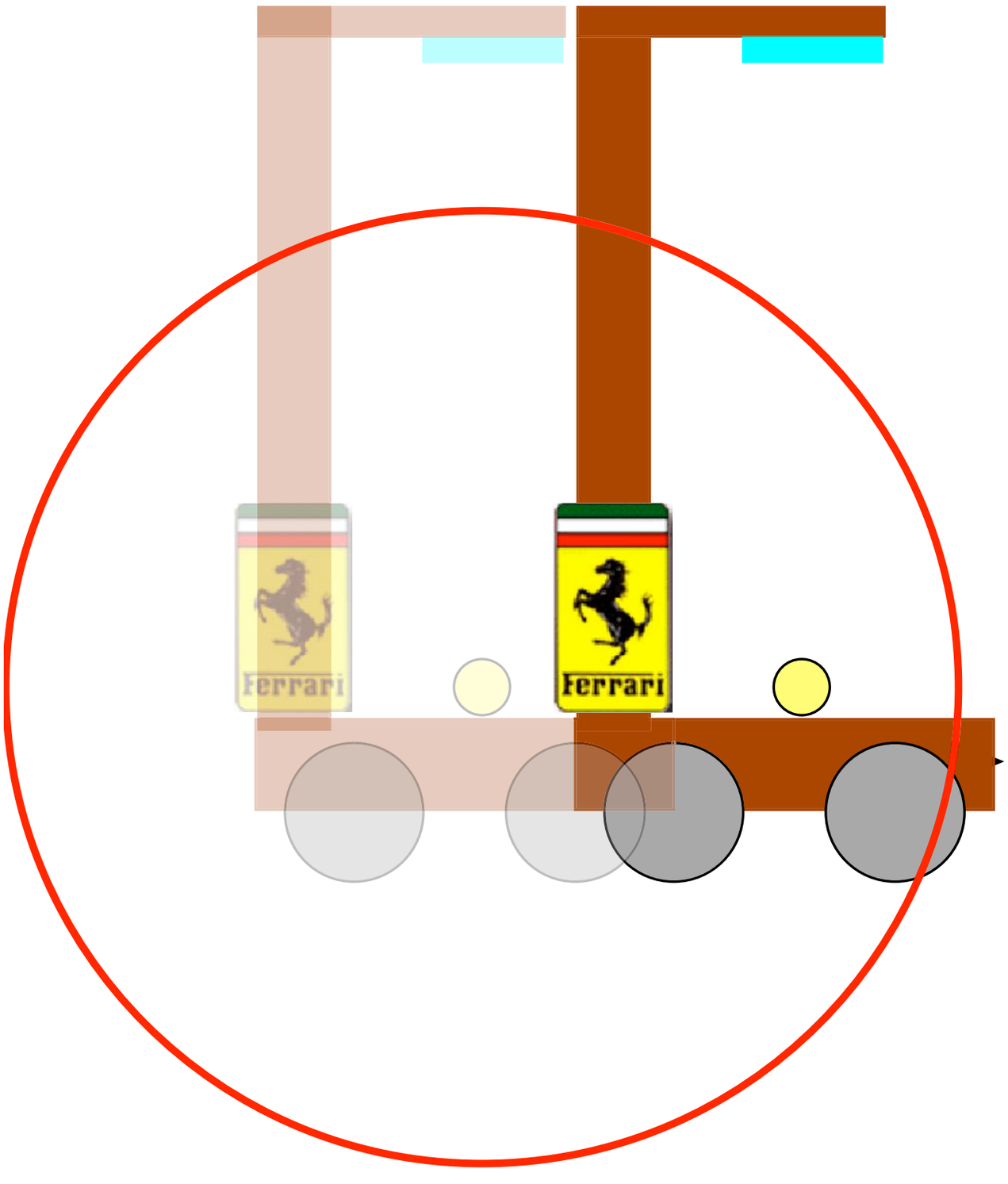
t=2.5 nsec



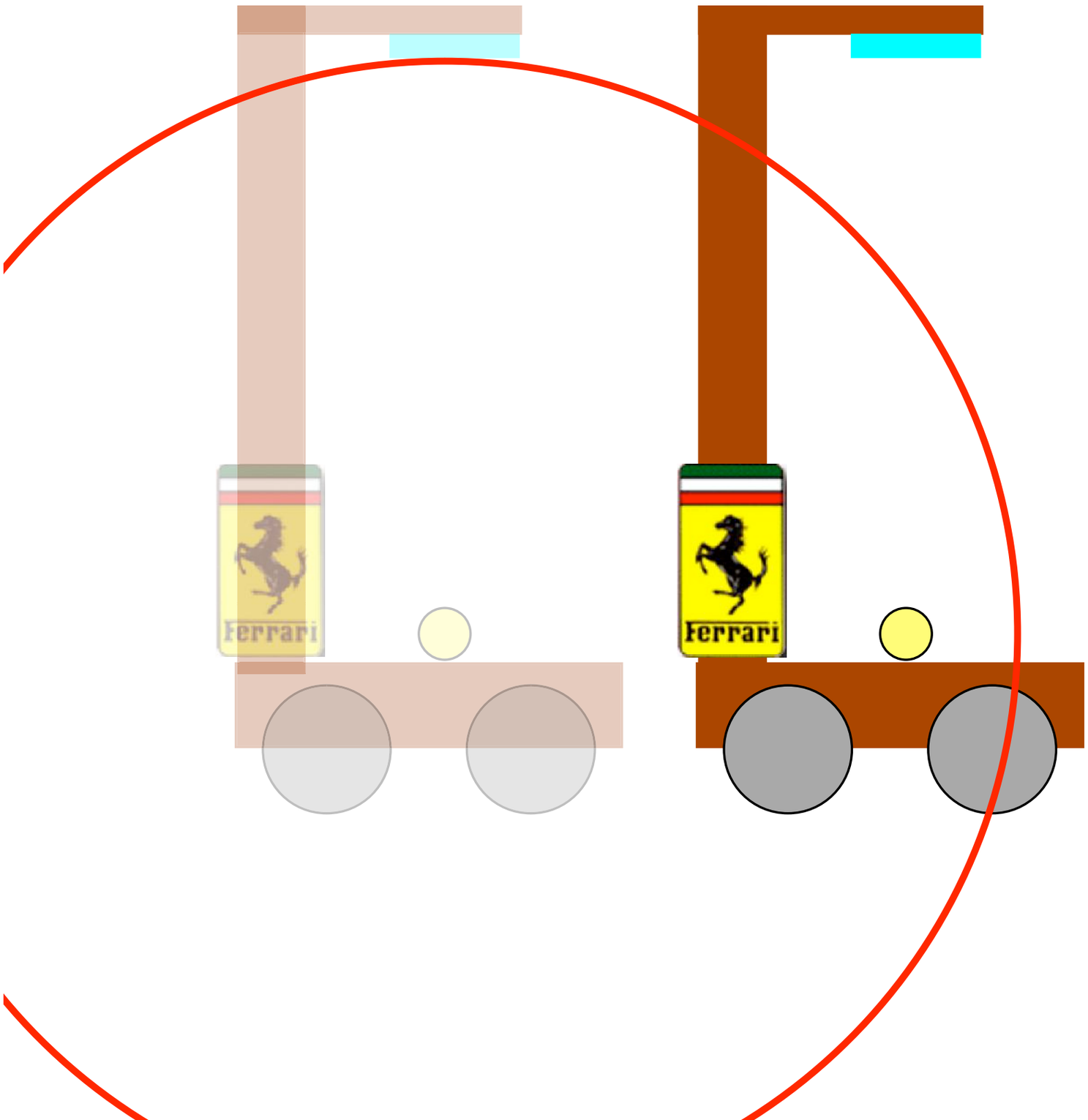
t=5.0 nsec



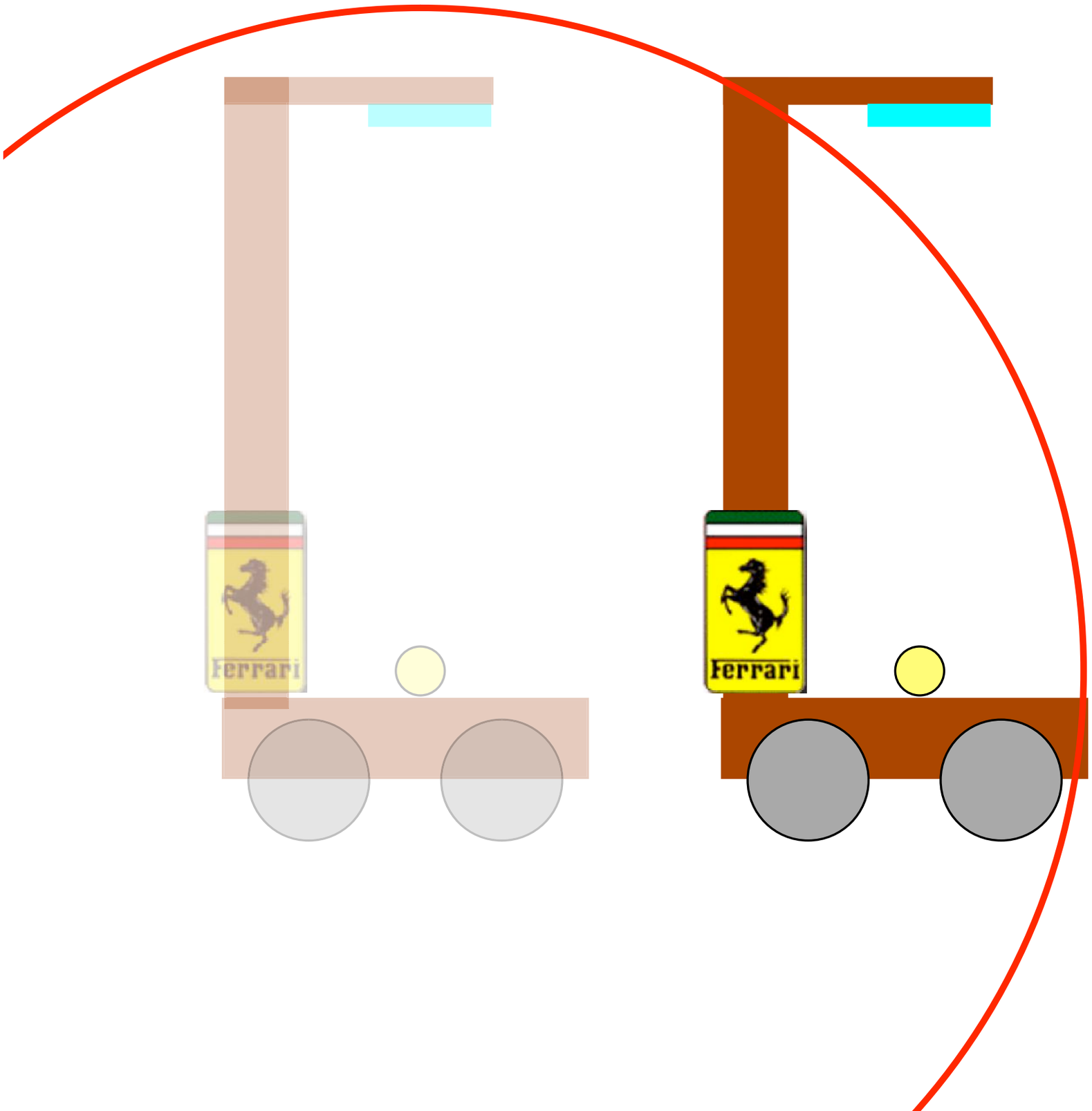
t=7.5 nsec



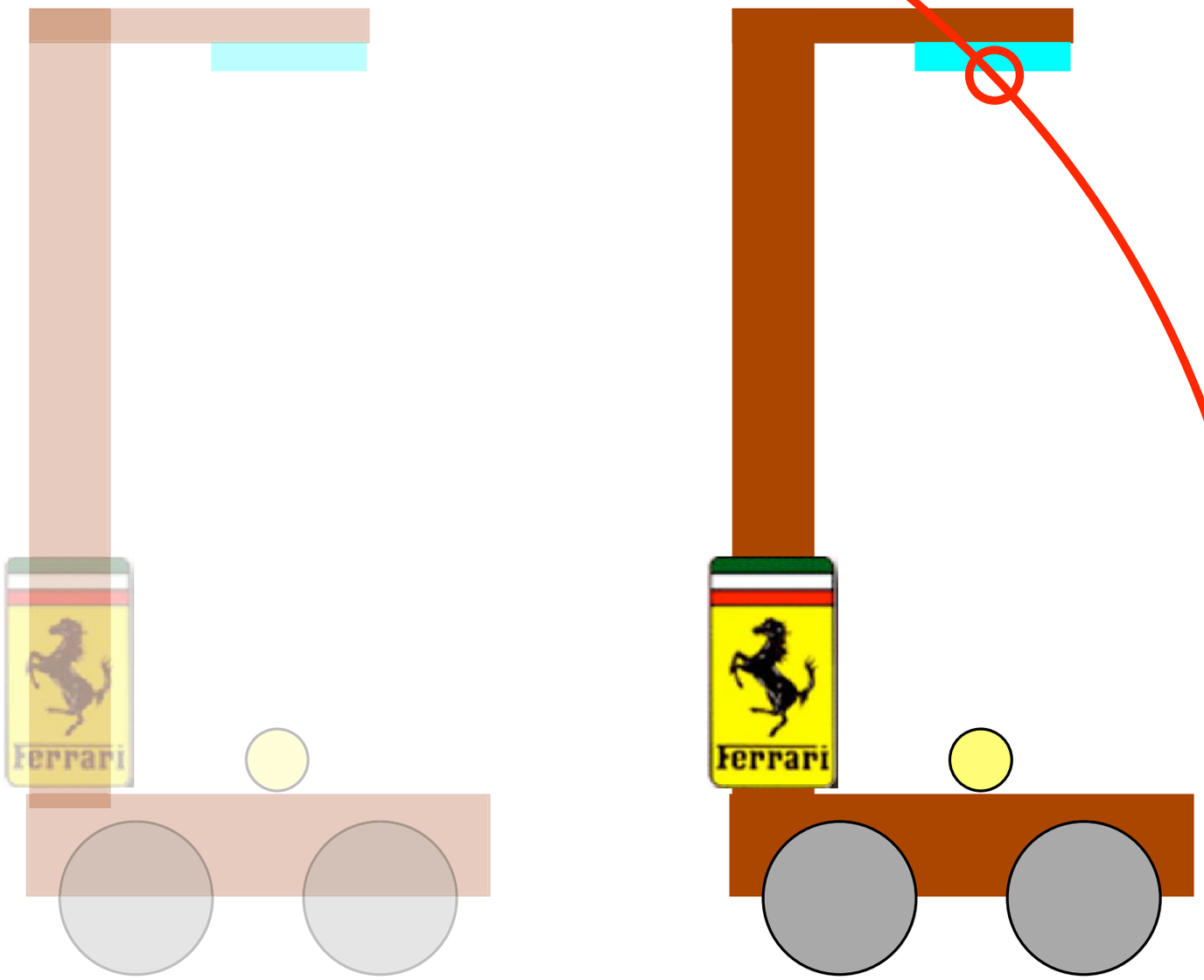
t=10.0 nsec



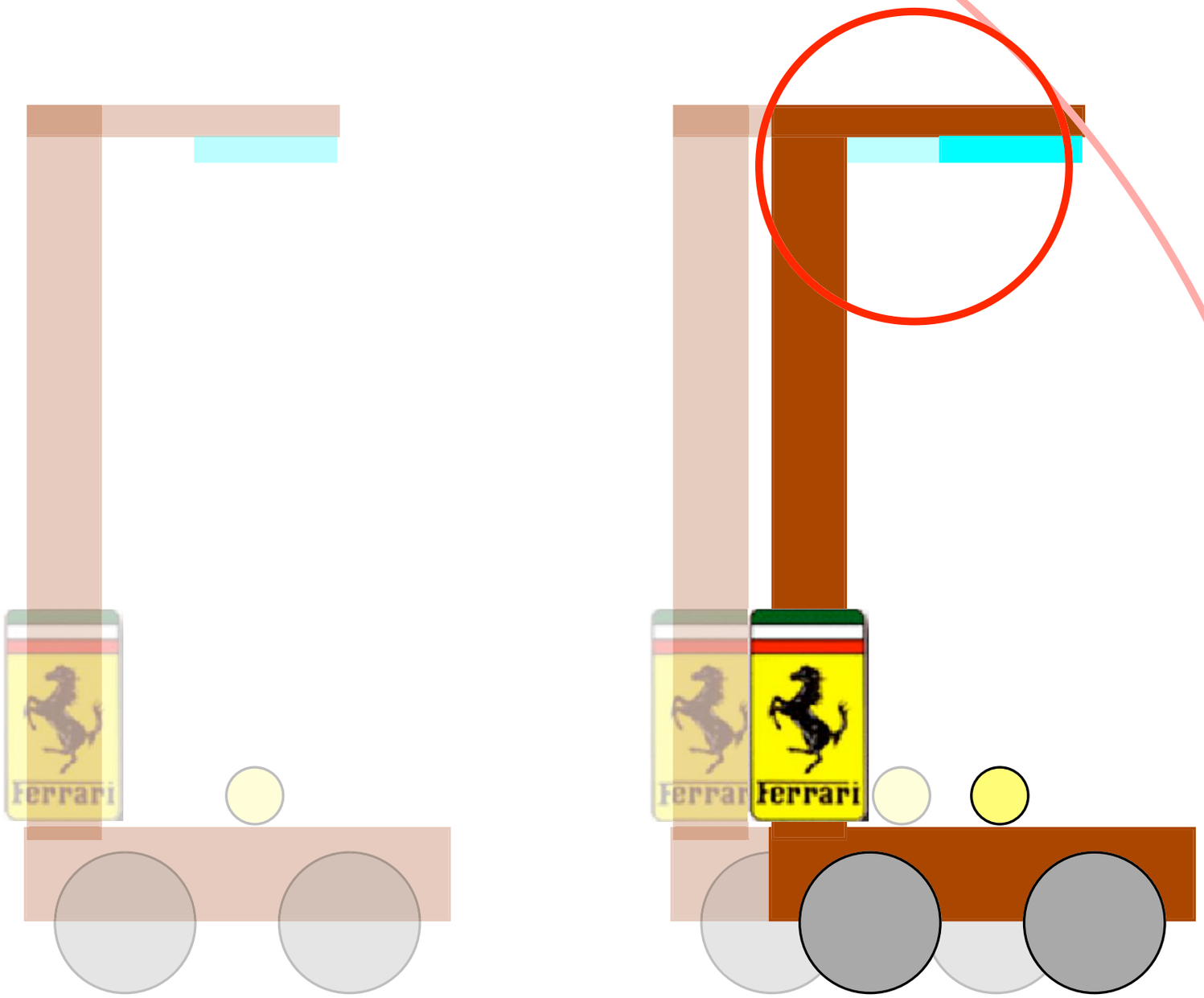
t=12.5 nsec



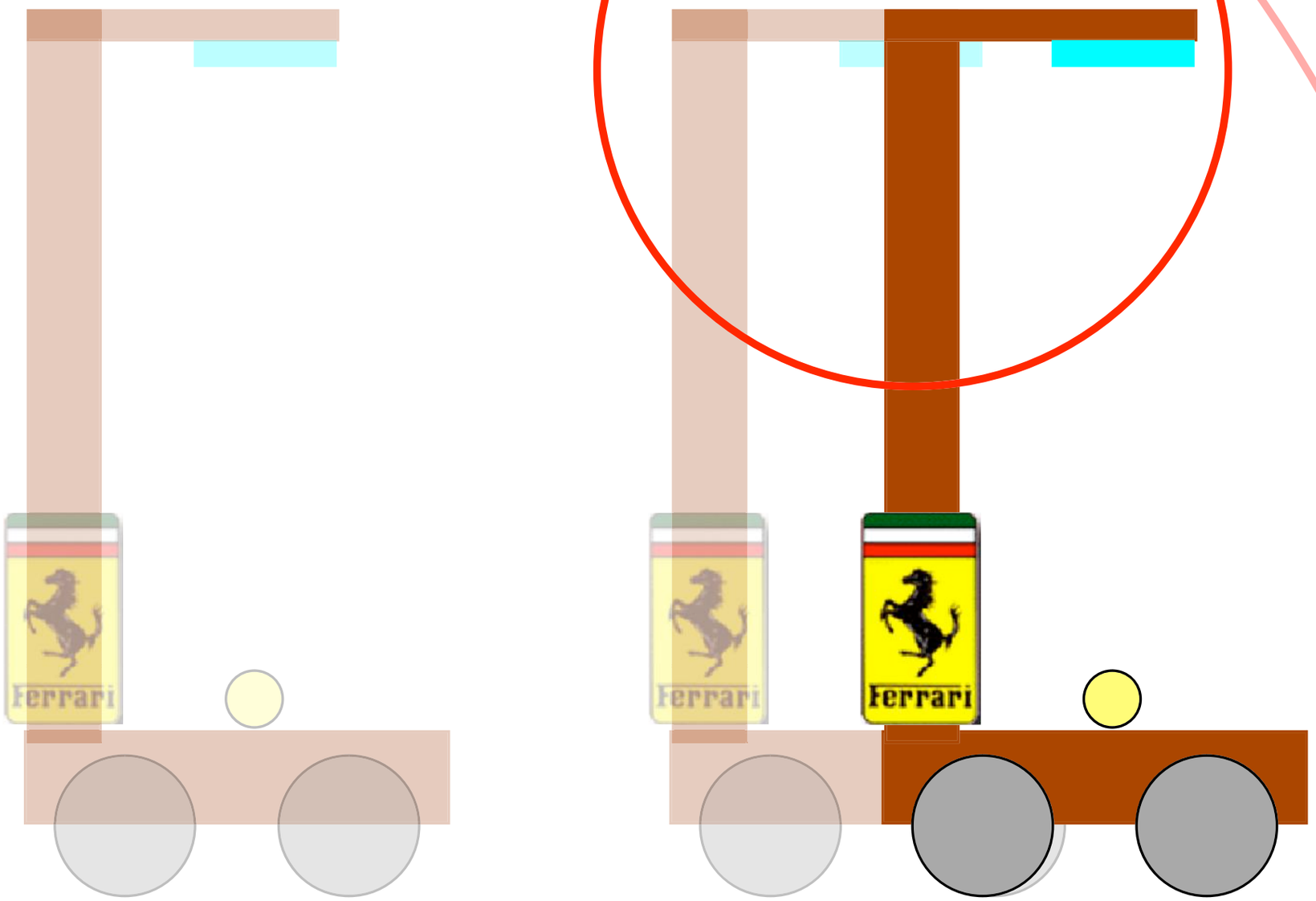
t=15.0 nsec



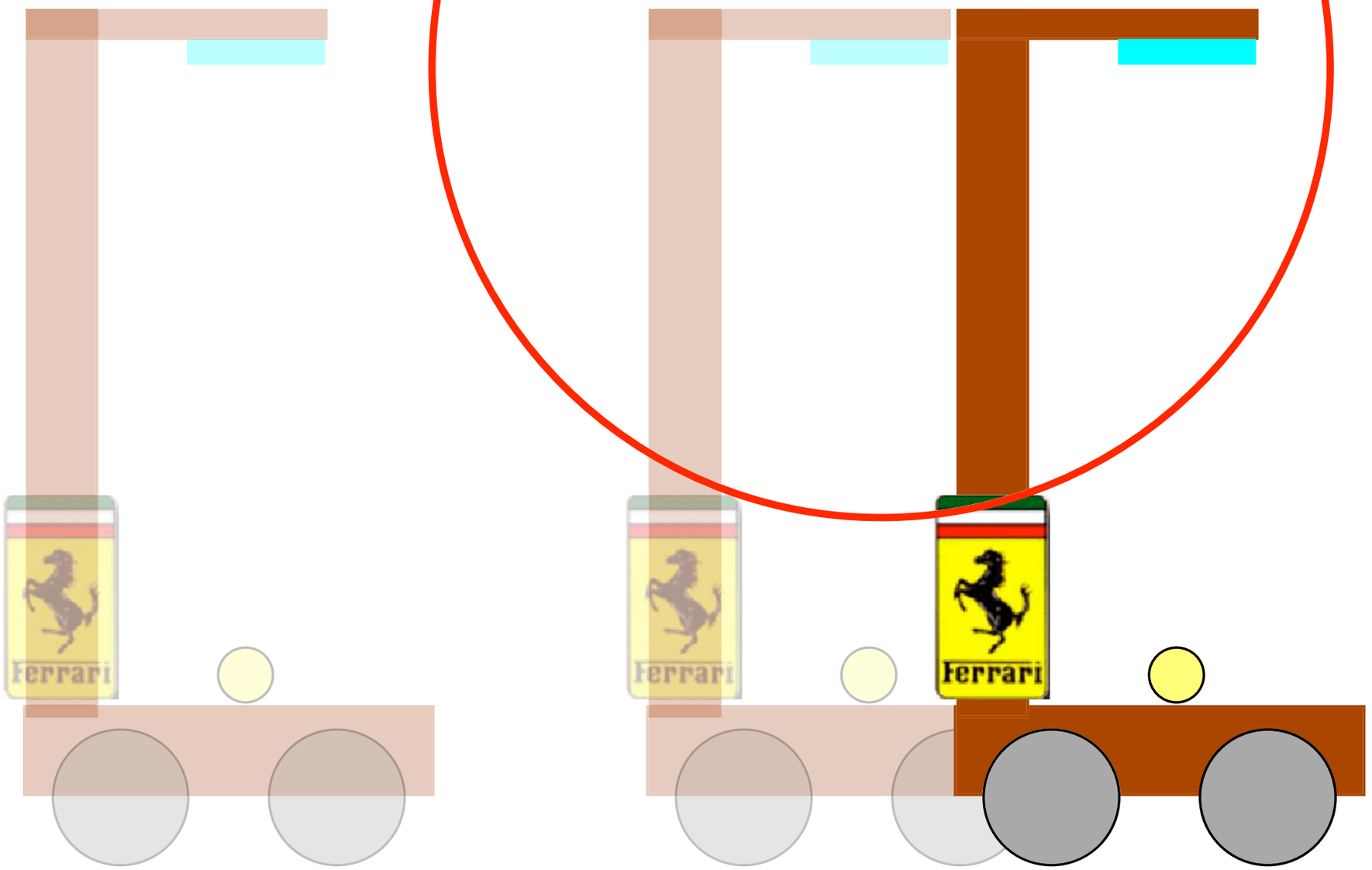
t=17.5 nsec



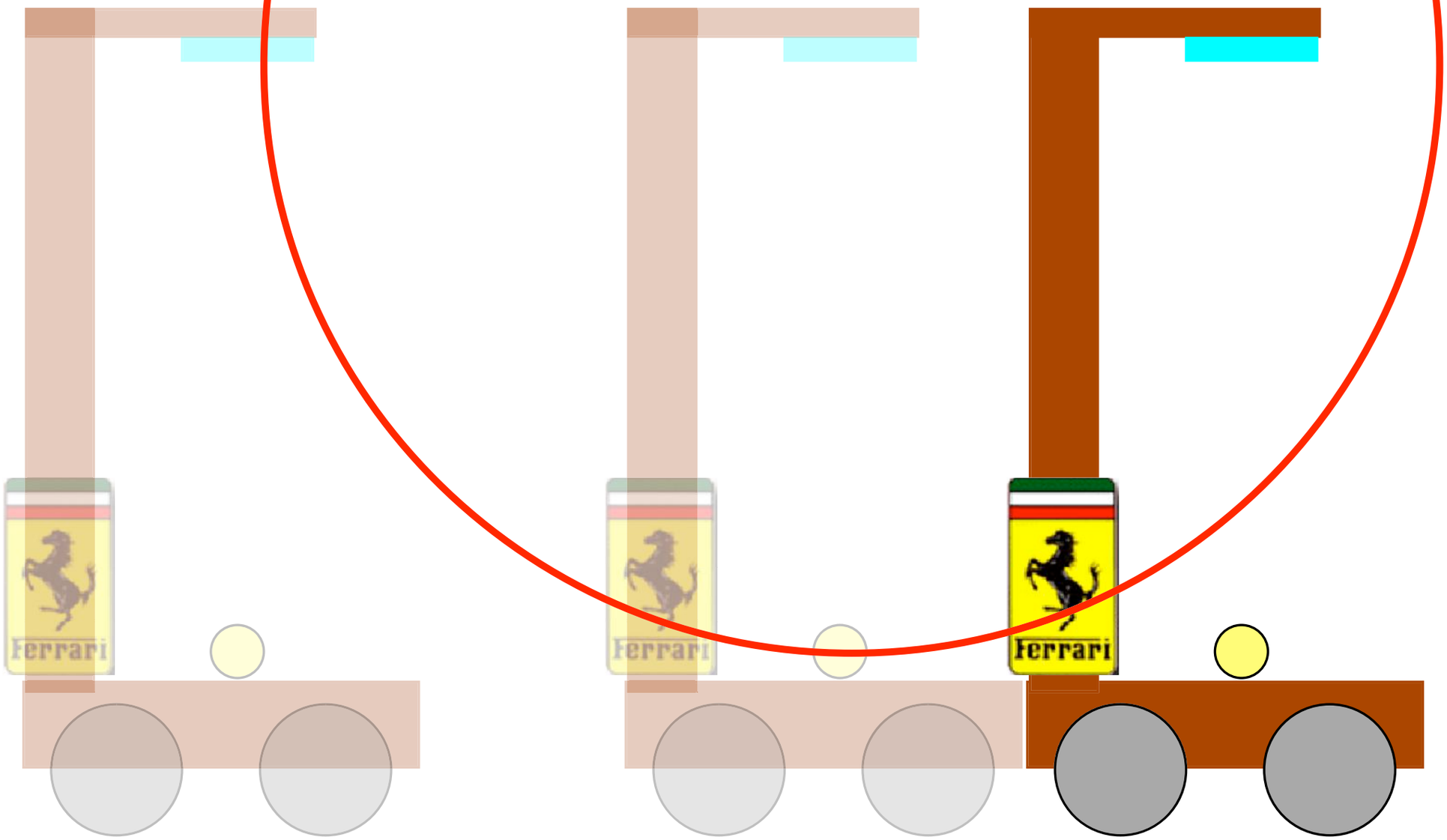
t=20.0 nsec



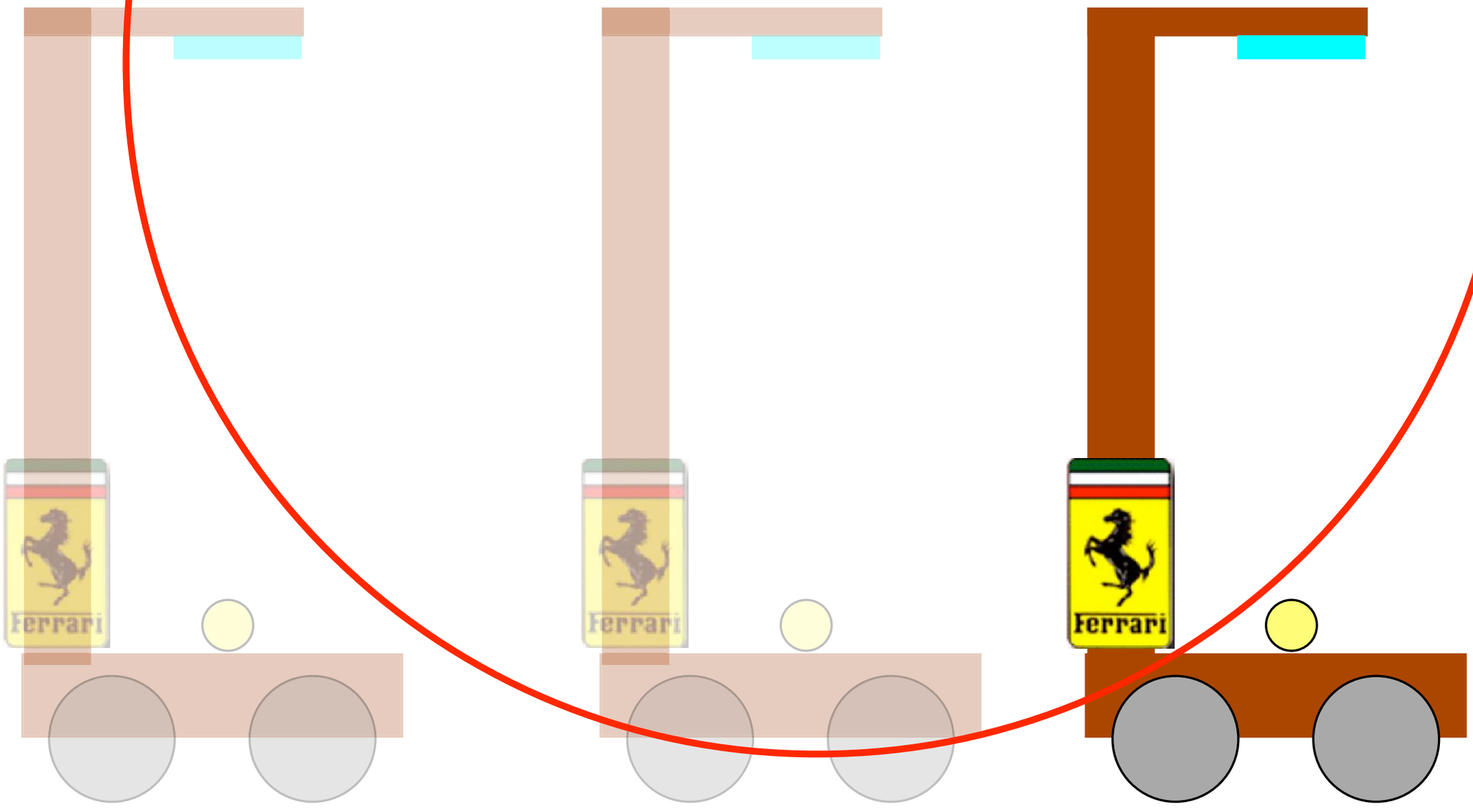
t=22.5 nsec



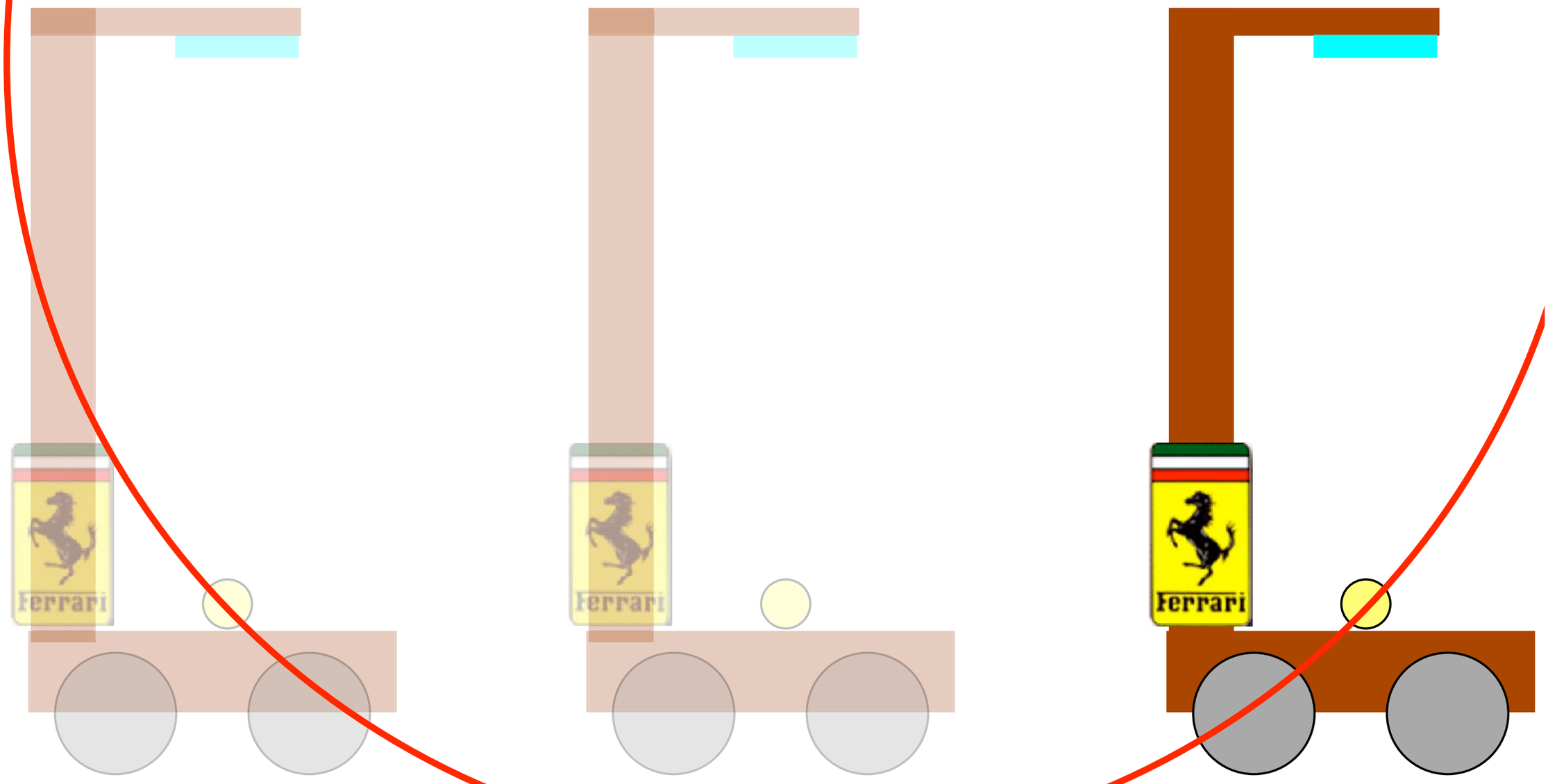
t=25.0 nsec



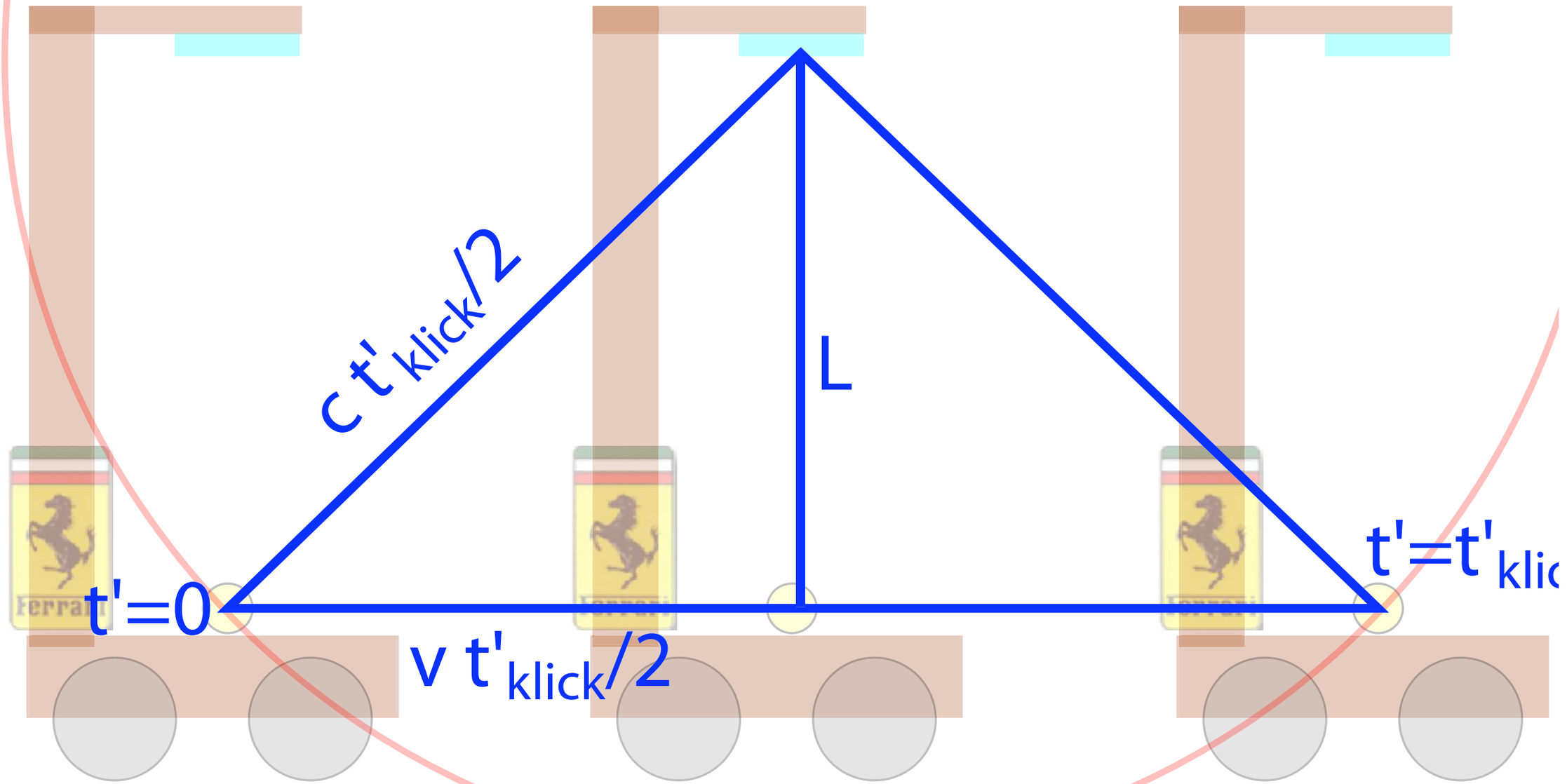
t=27.5 nsec



t=30.0 nsec



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



from experiment with car at rest we know:

$$L = ct_{click}/2$$

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

Solve for t' :

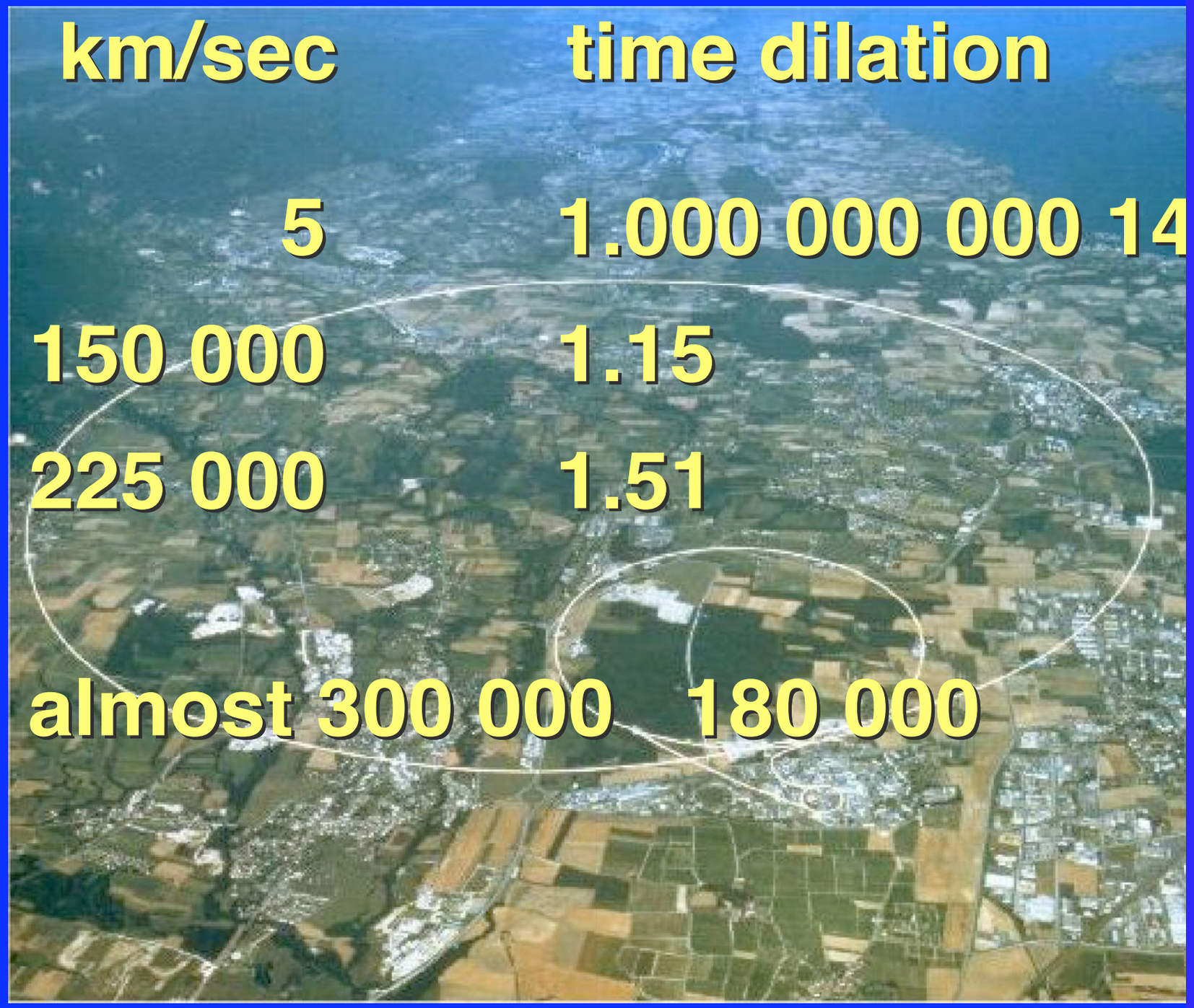
$$t' = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}}\, t$$

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:

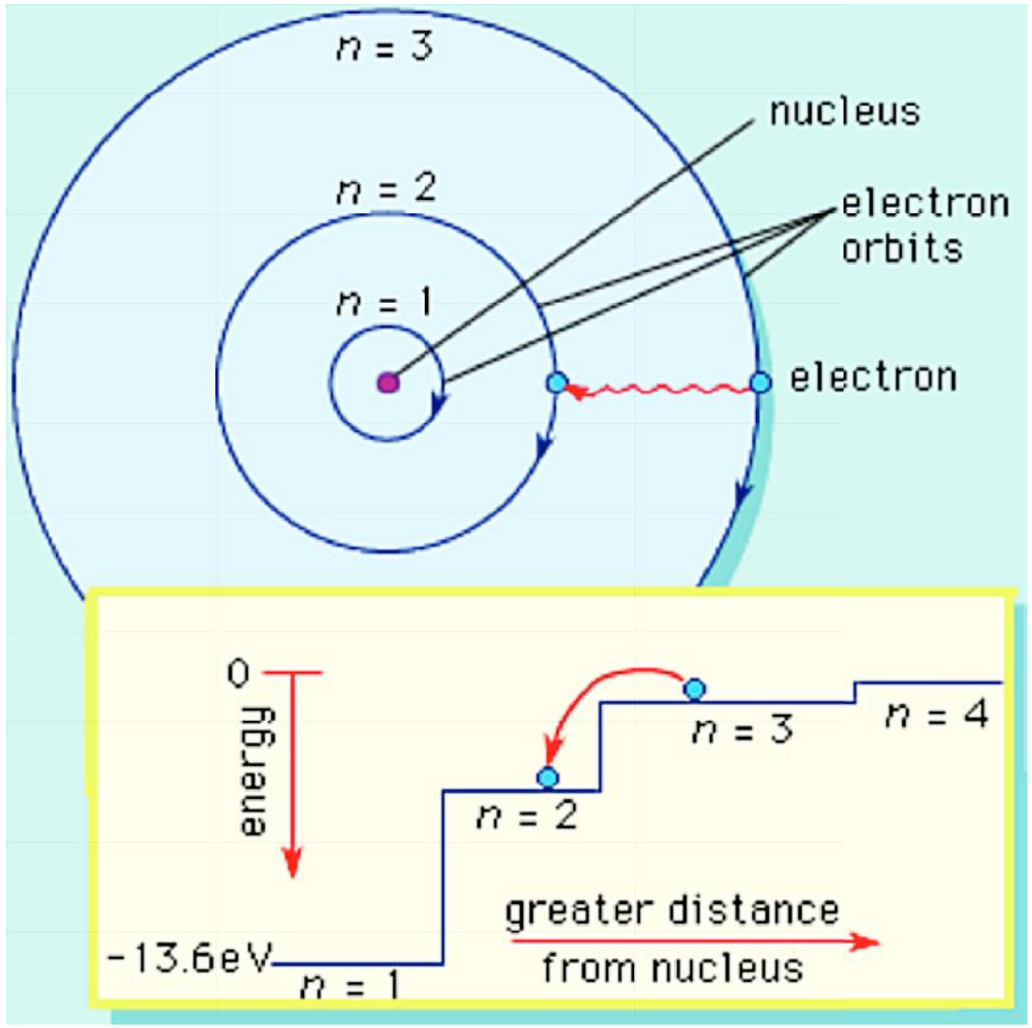
53 nsec

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)

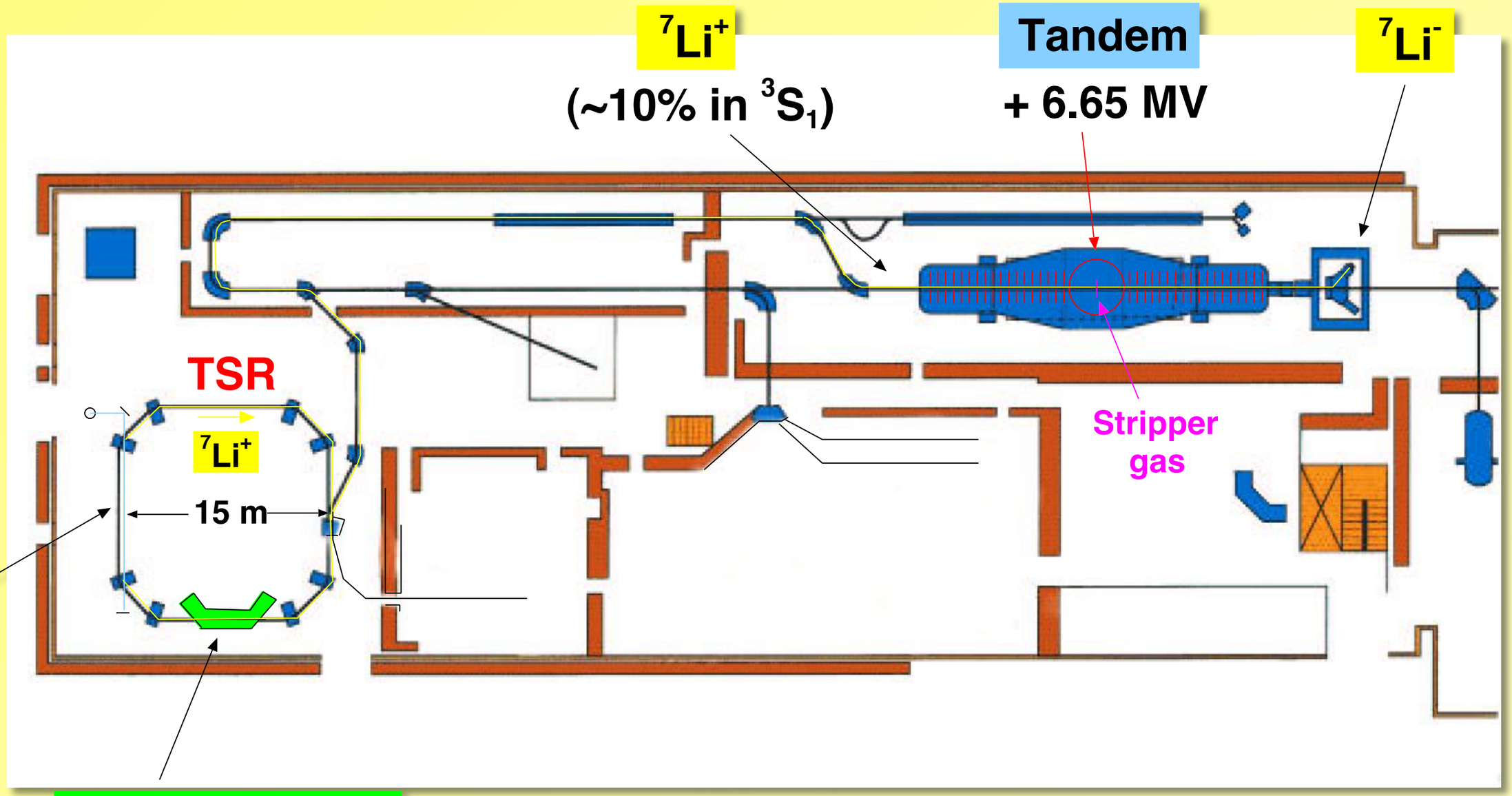


$$E = h\nu$$

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



$^7Li^+$ E = 13.3 MeV v = 19 000 km/sec

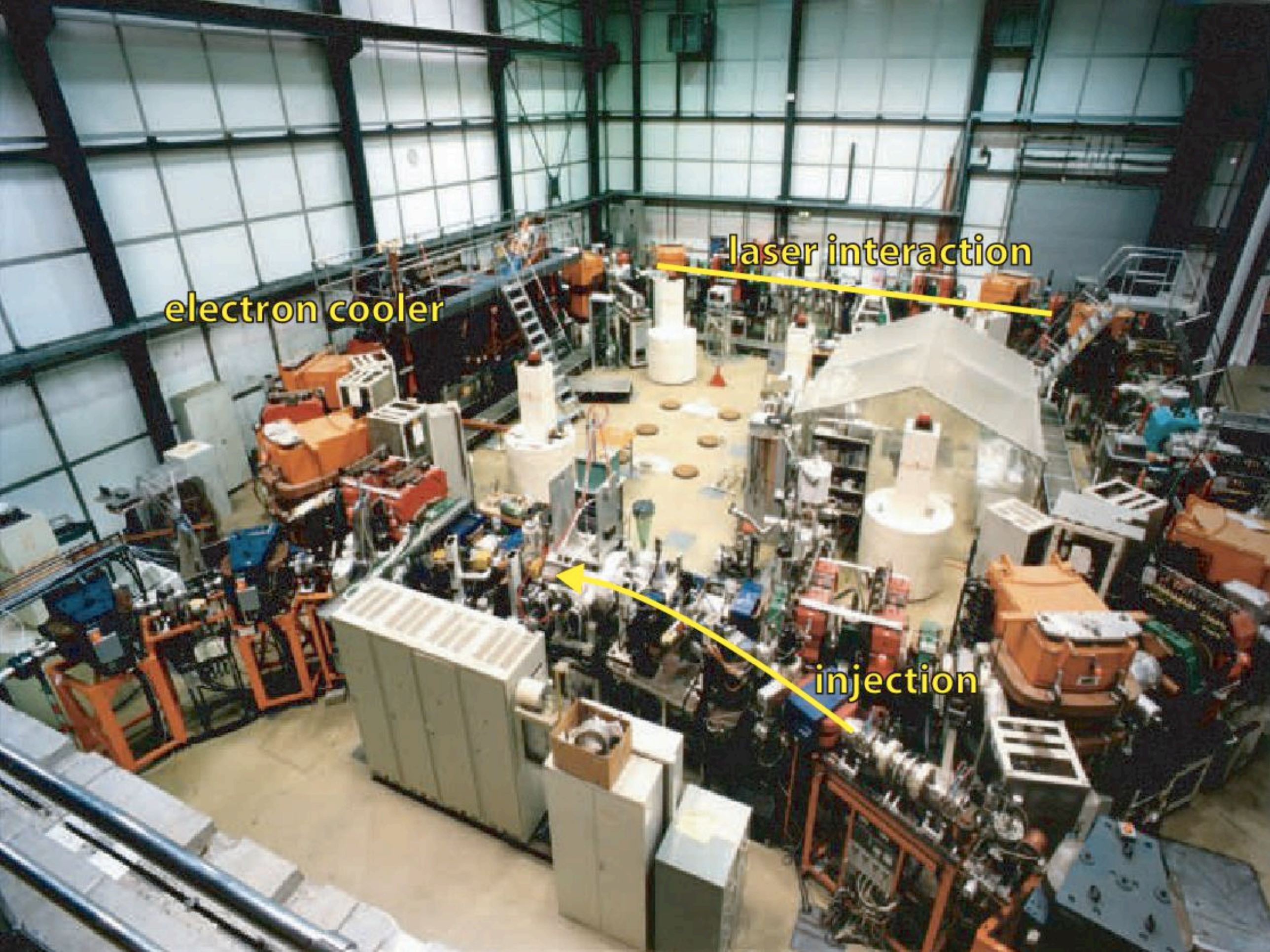
β = v/c = 0.064

Storage Time $t_{1/2}$ = 50 sec

Stored particles ~ 10^8

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

rel-beschleuniger-r

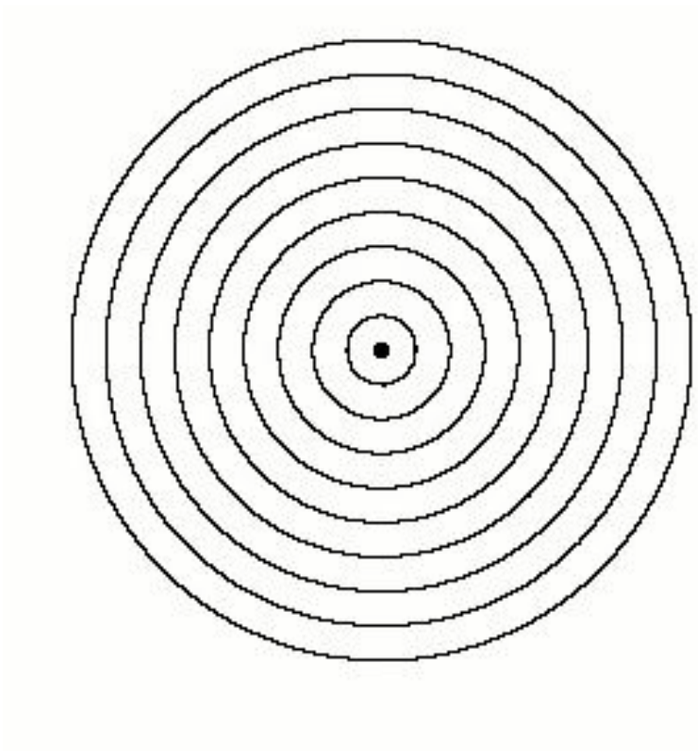

laser interaction
electron cooler
injection

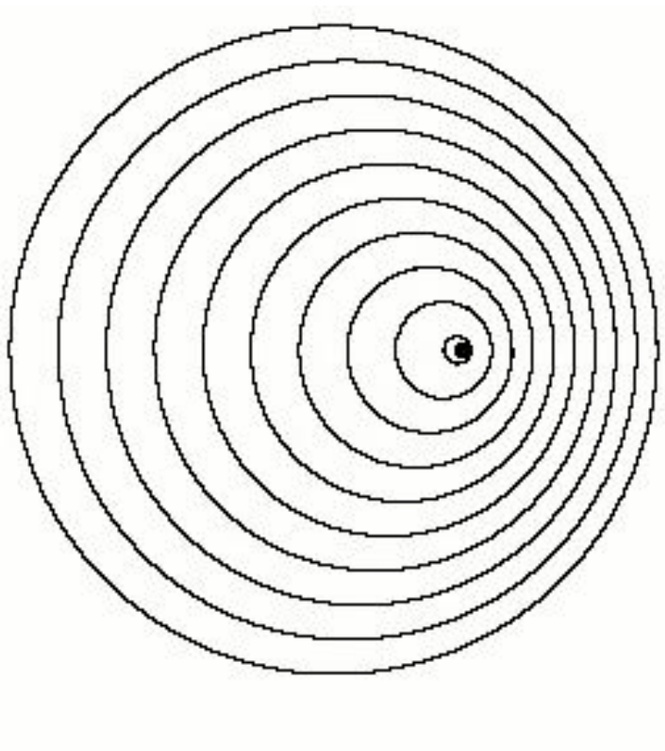
The Doppler Effect

Basic phenomenon: the frequency of sound (and other waves) changes depending on relative motion of the source and observer

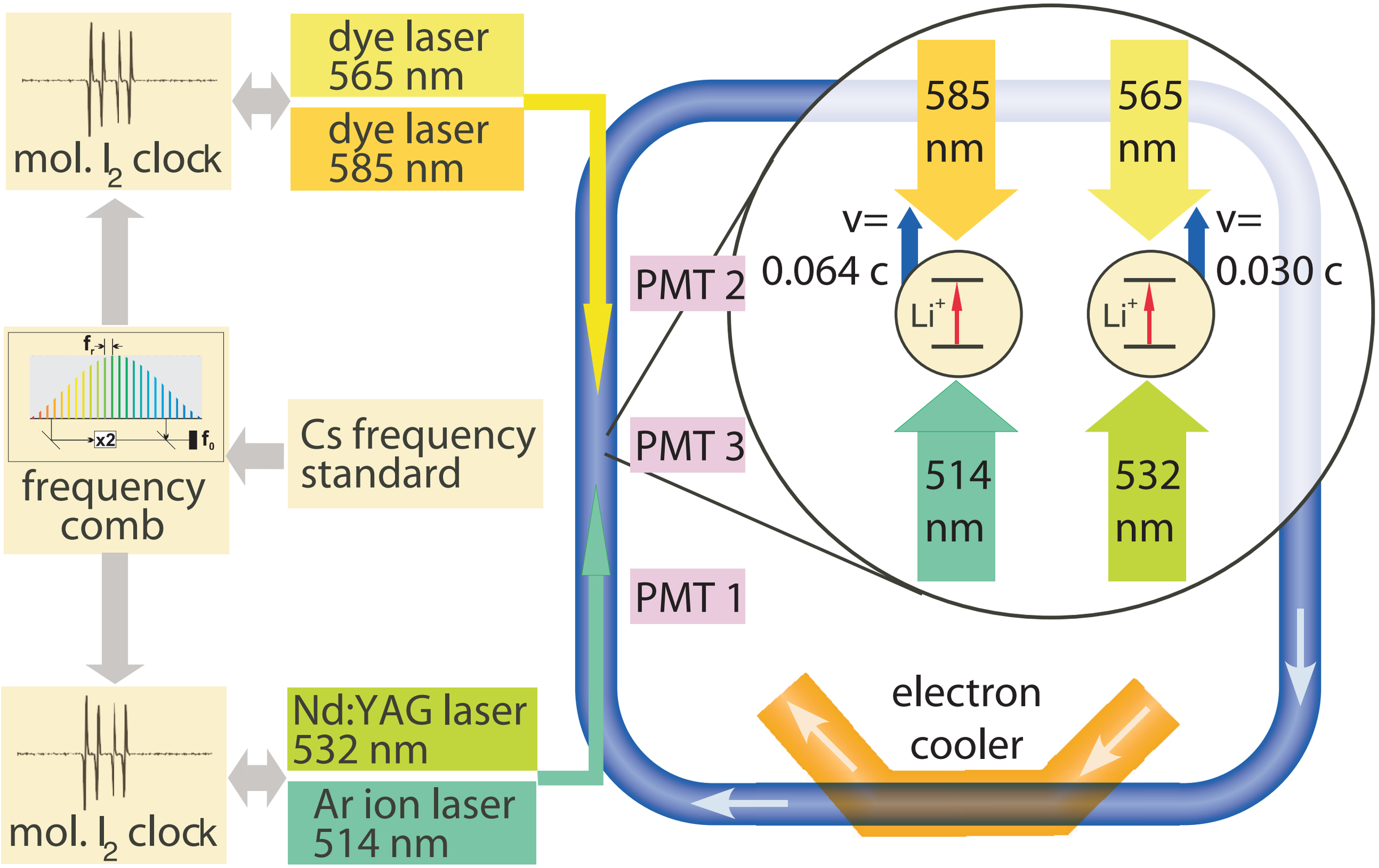
Everyday example: the pitch of a siren rises and then falls again as an emergency vehicle approaches you and then speeds away.

Sign of the effect: relative motion towards each other : f increases
" " away from " " : f decreases.





The new TSR dual-boost experiment



Most important part: checking all the systematic effects

and are often unexpected ...

They can kill you ...

Most important part: checking all the systematic effects

They can kill you ...

Test of relativistic time dilation with fast optical atomic clocks at different velocities

SASCHA REINHARDT[1], GUIDO SAATHOFF[1], HENRIK BUHR[1], LARS A. CARLSON[1], ANDREAS WOLF[1], DIRK SCHWALM[1], SERGEI KARPUK[2], CHRISTIAN NOVOTNY[2], GERHARD HUBER[2], MARCUS ZIMMERMANN[3], RONALD HOLZWARTH[3], THOMAS UDEM[3], THEODOR W. HÄNSCH[3] AND GERALD GWINNER[4]*

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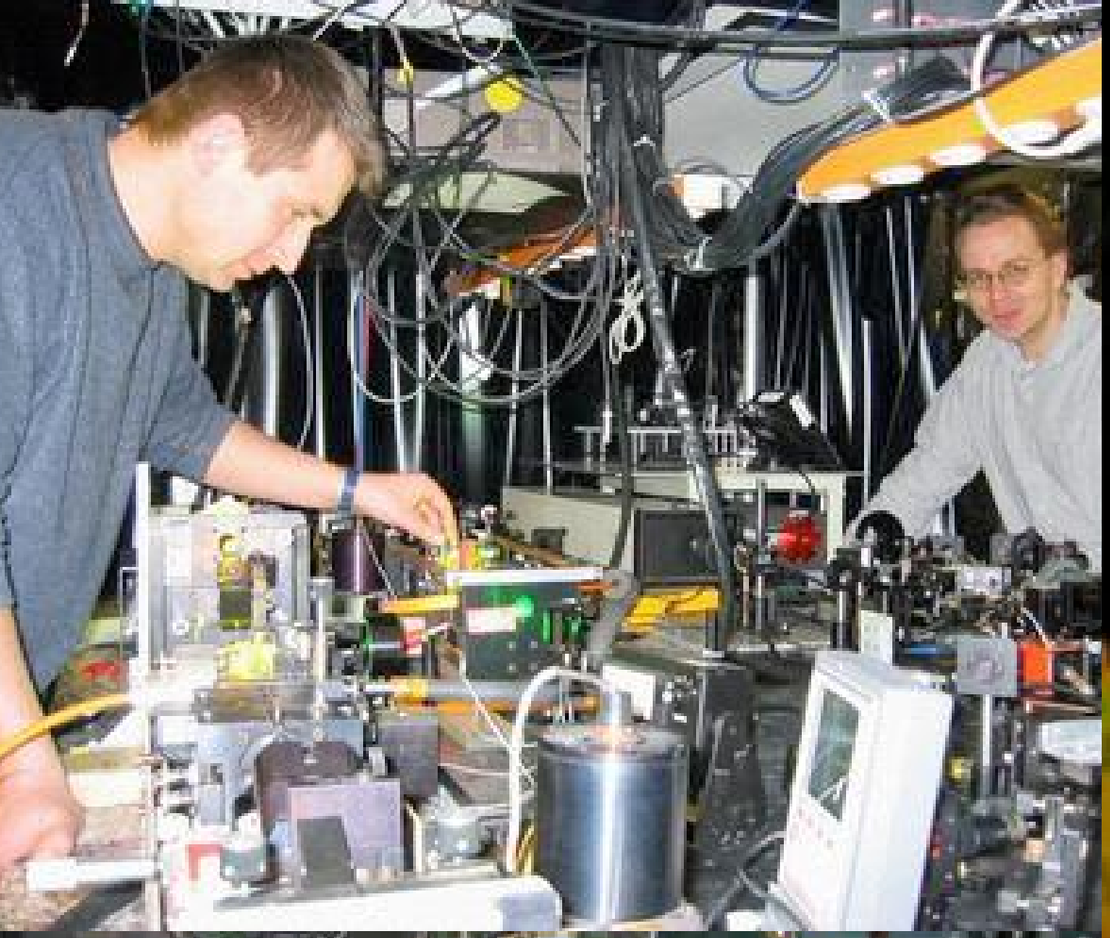
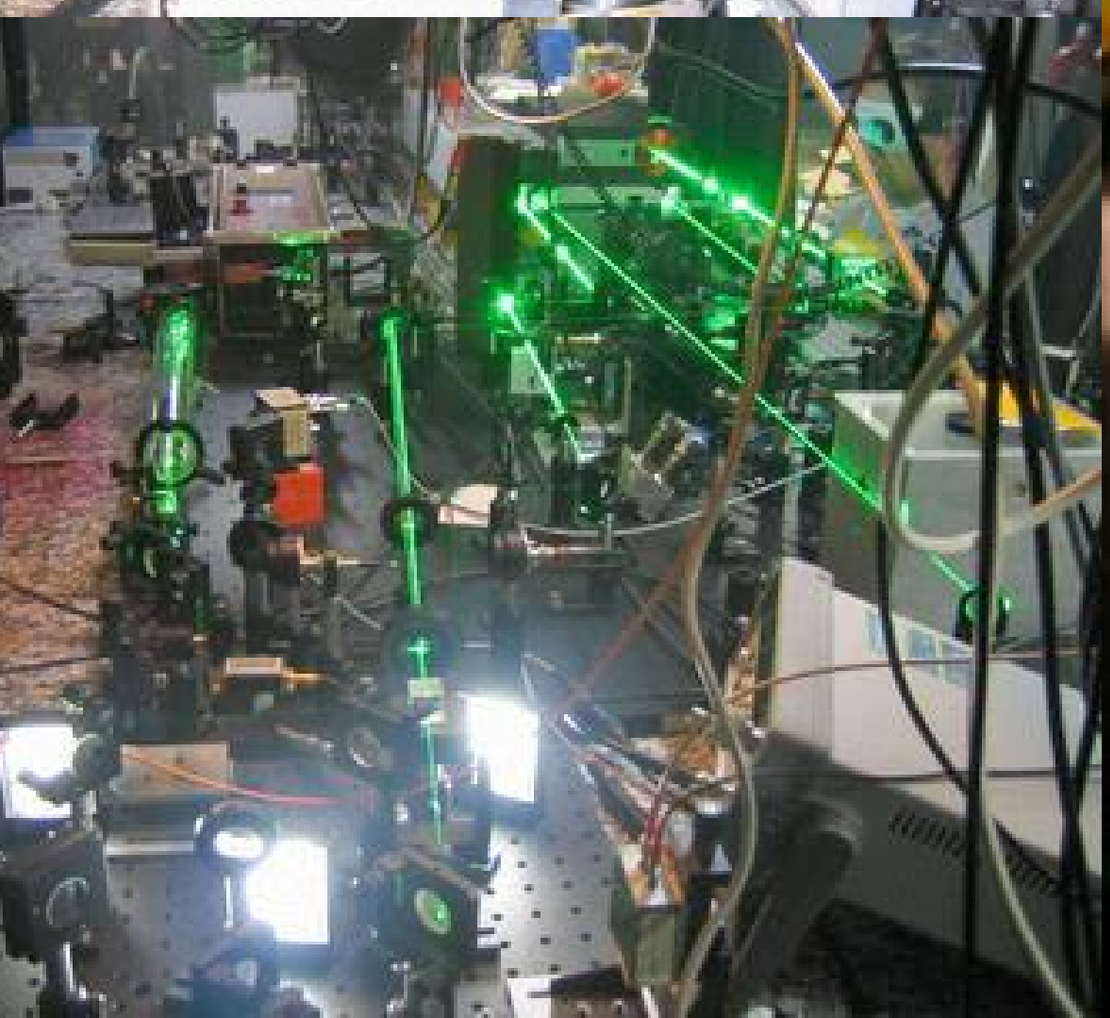
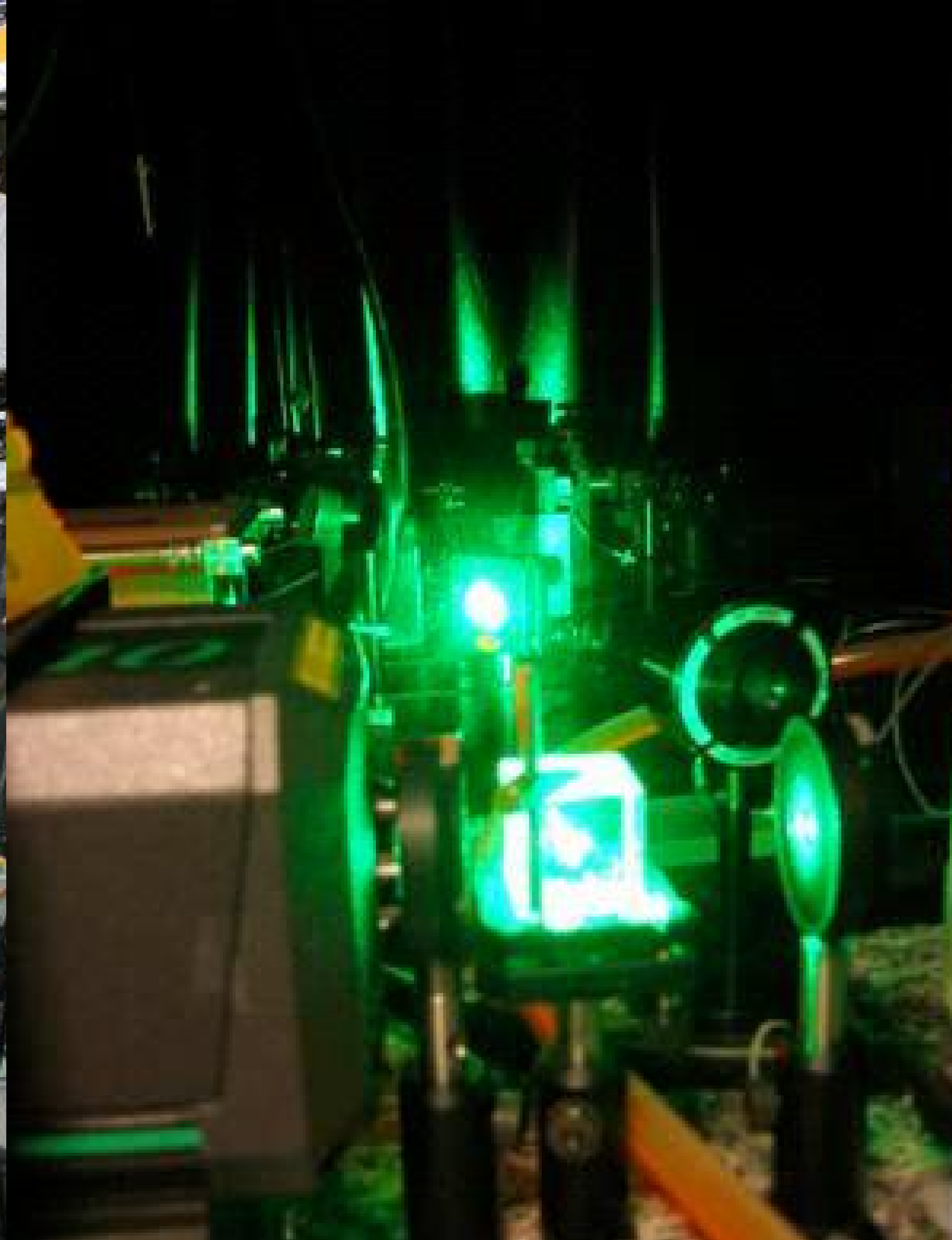
confirm Special Relativity at the 10 ppb level

Published online: 11 November 2007; doi:10.1038/nphys778

Time dilation is one of the most fascinating aspects of special relativity as it abolishes the notion of absolute time. It was first observed experimentally by Ives and Stilwell in 1938 using the Doppler effect. Here we report on a method, based on fast optical atomic clocks with large, but different Lorentz boosts, that tests relativistic time dilation with unprecedented precision. The approach combines ion storage and cooling with optical frequency counting using a frequency comb. $^{7}Li^{+}$ ions are prepared at 6.4% and 3.0% of the speed of light in a storage ring, and their time is read with an accuracy of 2×10^{-10} using laser saturation spectroscopy. The comparison of the Doppler shifts yields a time dilation measurement represented by a Mansouri–Sexl parameter $|\hat{\alpha}| \leq 8.4 \times 10^{-8}$, consistent with special relativity. This constrains the existence of a preferred cosmological reference frame and CPT- and Lorentz-violating 'new' physics beyond the standard model.







Winnipeg Free Press

... in just seven years

From nightmare to dream

Bomber kicker Troy Westwood is mobbed by teammates Sunday after booting the game-winning field goal.

... in just four seconds!

It hasn't been the smoothest of seasons for Troy Westwood. But things looked pretty rosy after the Bomber kicker nailed a field goal in the dying seconds yester-

Izumi north

Famed fisherman might buy homes in Leaf Rapids denied to First Nations / A4

10,000 times yes

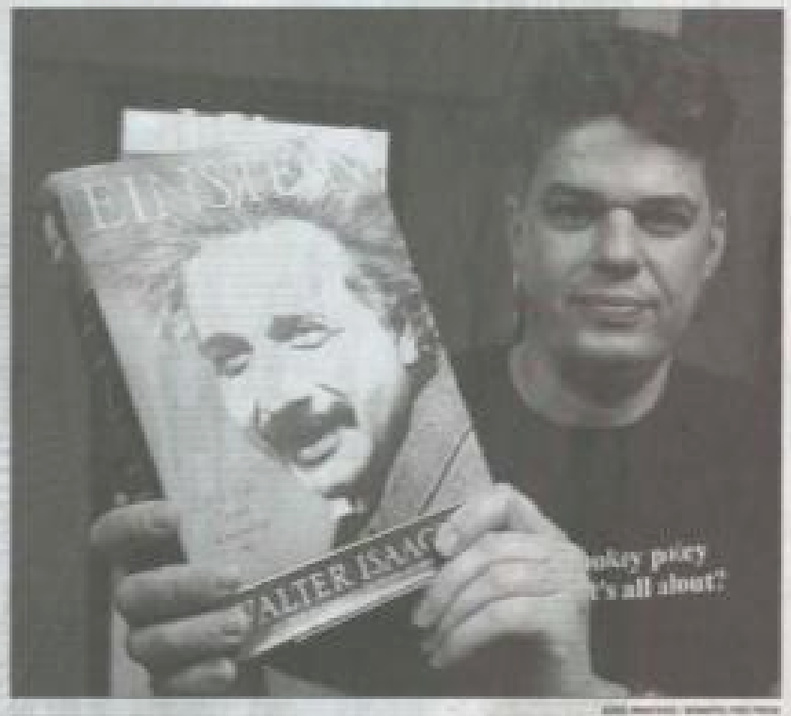
A U of M prof helps prove Einstein's theory is really, really accurate

A6

Einstein so right, team proves

U of M prof helps nail down relativity

By Nick Martin



GOOD news, Dr. Einstein — University of Manitoba physics Prof. Gerald Gwinner gave you a pass this weekend on your theory of relativity.

Gwinner headed an international team of physicists who have used a particle accelerator in Germany to make the most accurate measurements so far of time dilation, thus confirming Albert Einstein's theory of relativity.

They published their findings Sunday in the academic journal Nature Physics.

Gwinner said researchers verified Einstein's theory as far back as 1938, to a margin of error of one per cent.

But "we have an accuracy now of 10 to the minus seventh, or 10,000 times that."

Gwinner laughed that sometimes "our brains do not work" when they try to grasp the concepts that Einstein explored.

"Relativity is especially very fascinating," he said. "Time dilation is so weird — our daily experience tells us things are simpler than they are."

Time dilation, in lay terms, can be illustrated by comparing how time moves on a ticking watch on a person's wrist when that person stands still, relative to how time moves on a watch worn by a person in a moving car. They move differently, Gwinner said.

"A moving clock appears to be moving more slowly. To the observer, it is going more slowly," he said. "There is no absolute time."

The difference is unbelievably tiny, he said, possibly in the billionths of a second.

Another illustration involves twins born at exactly the same time. A twin remaining on Earth would age more quickly than the twin who flew to a star and back at speeds approaching the speed of light, Gwinner said.

In practical terms, he said, "one thing that depends on relativity in modern life is the GPS system," which uses satellites moving in space at high speeds while measuring precise locations on Earth.

"Time dilation plays a role. That has to be put into the software," Gwinner said.

As experiments become more sophisticated and precise in their measurements, the work his team has done could help lead to knowledge of super string and quantum gravity theories, he said.

He said those are all part of figuring out how the universe was born, what it's all about, and where it's going.

The big-bang theory posits that matter and anti-matter should have been created in equal amounts, he said. Trouble is, scientists have created anti-matter in the lab, but can't find it in the universe, at least so far.

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U of M physics professor Gerald Gwinner is part of an international team that has proven Einstein's (in photo) theory of relativity has an accuracy of 10-to-the-minus-seventh.

sci.physics.relativity

How many idiots does it take to confirm an idiocy like RT ?

Options

Messages 1 - 25 of 36 - Collapse all Newer >

qbit View profile (5 users) More options Aug 24, 12:52 am

A team of 14 (!) people have done an experiment and
have published their earth-shaking (sic :-) result on
exactly one (yes 1 (!), ie. a single) page, titled:
"Experimental Test of Special Relativity" by
G. Saatho, S. Karpuk, S. Reinhardt, U. Eisenbarth, I. Hoog,
G. Huber, S. Krohn, R. Mu~noz-Horta, J. Lassen, D. Schwalm,
M. Weidemüller, A. Wolf, S. Wricke and G. Gwinner
--> http://www.mpi-hd.mpg.de/ato/ib02_pdf/ions-10.pdf

I strongly doubt the correctness of this experiment!

Whoever believes that paper can IMO be only an idiot!

Unbelievable! It was even accepted by Phys. Rev. Lett. 91,
190403 (2003) !!!
How is such an idiocy possible????!!!!

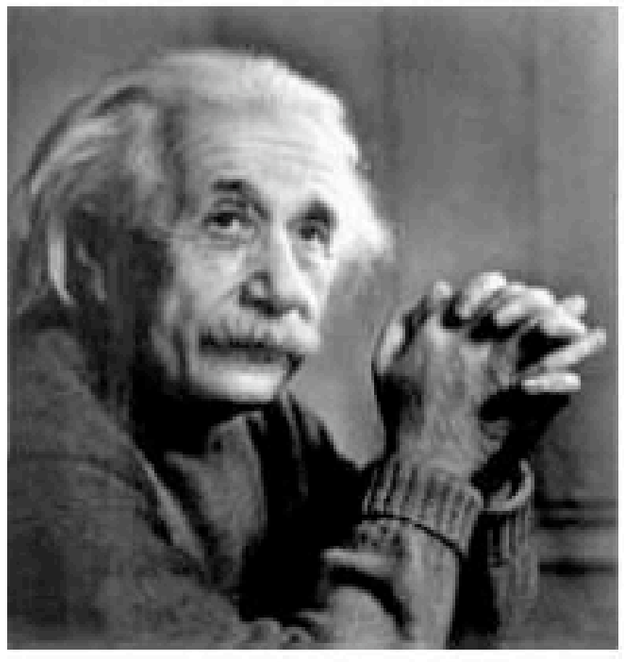
--
Physikalische 'Wahrheiten' direkt aus der
Volksverarschungsanstalt!

>I strongly doubt the correctness of this experiment!

How can someone who has never even studied calculus be fit to
make
such a qualification?

2007/11/11

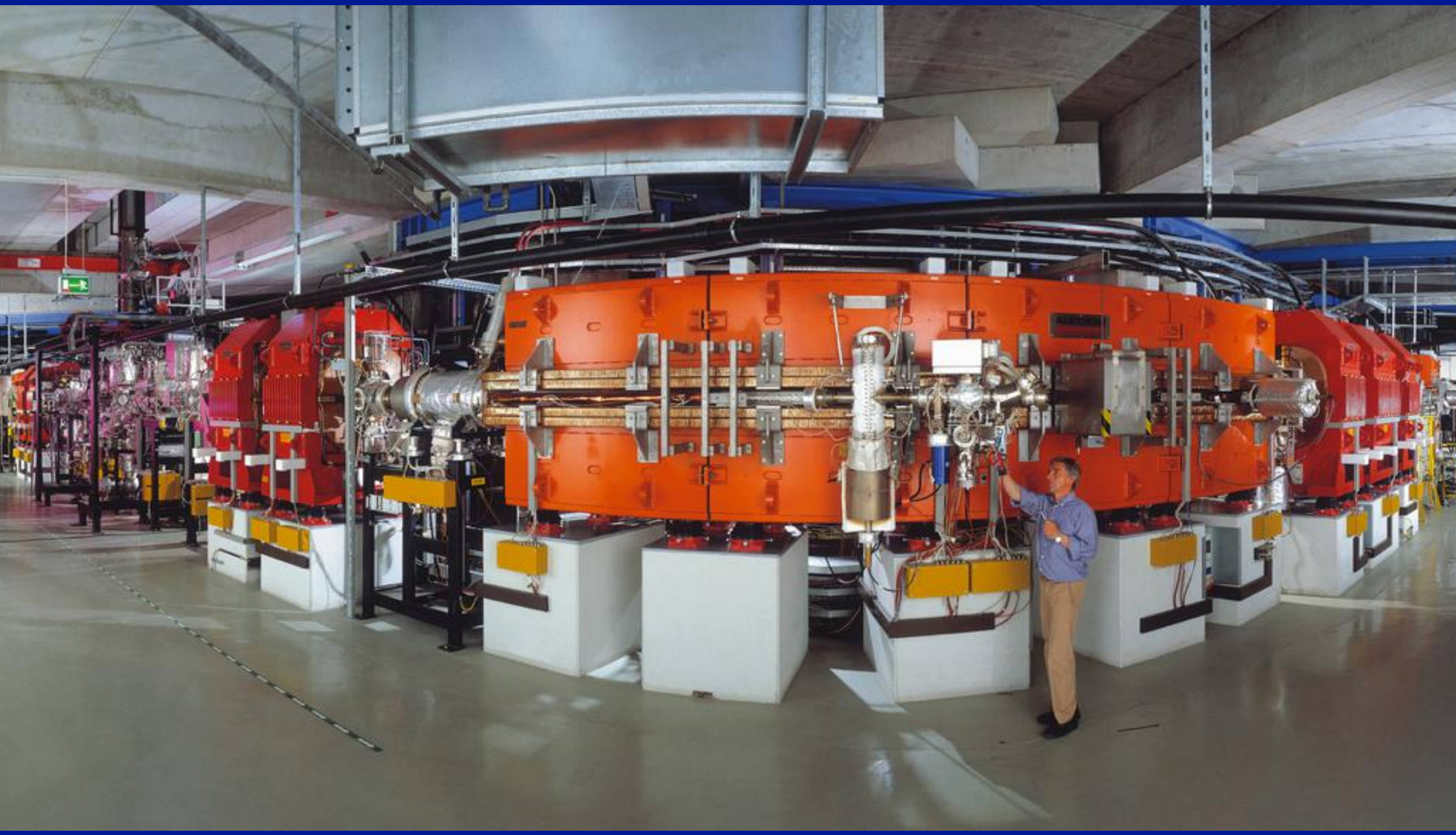
It's a century late, but Einstein's still on time



11:03:06 Þ.Ù

"After two hours, I looked at my watch," a reviewer of Wagnerian opera is said to have written. "I found that 17 minutes had gone by."

What's next? Li^+ in the ESR at β=0.34

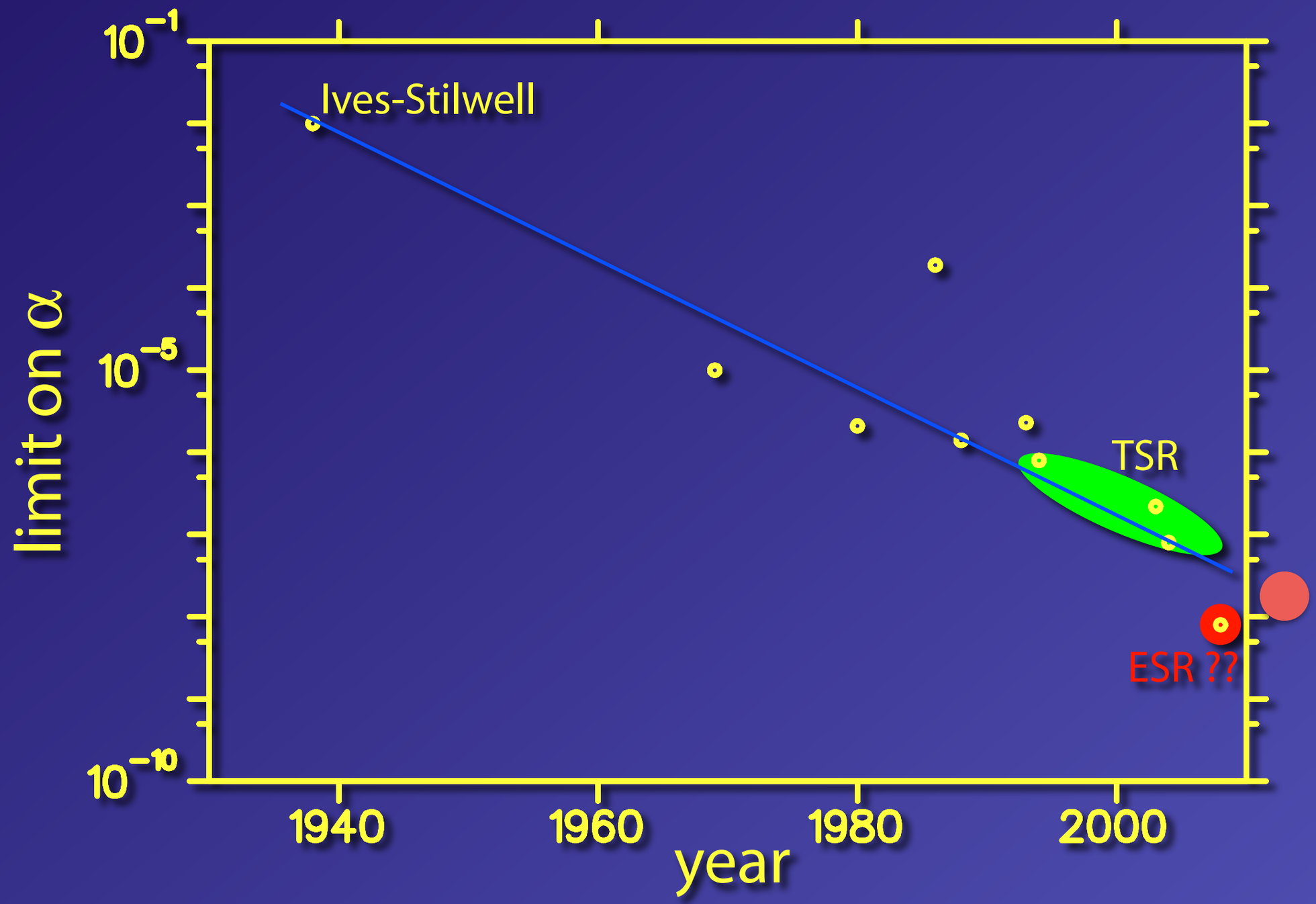


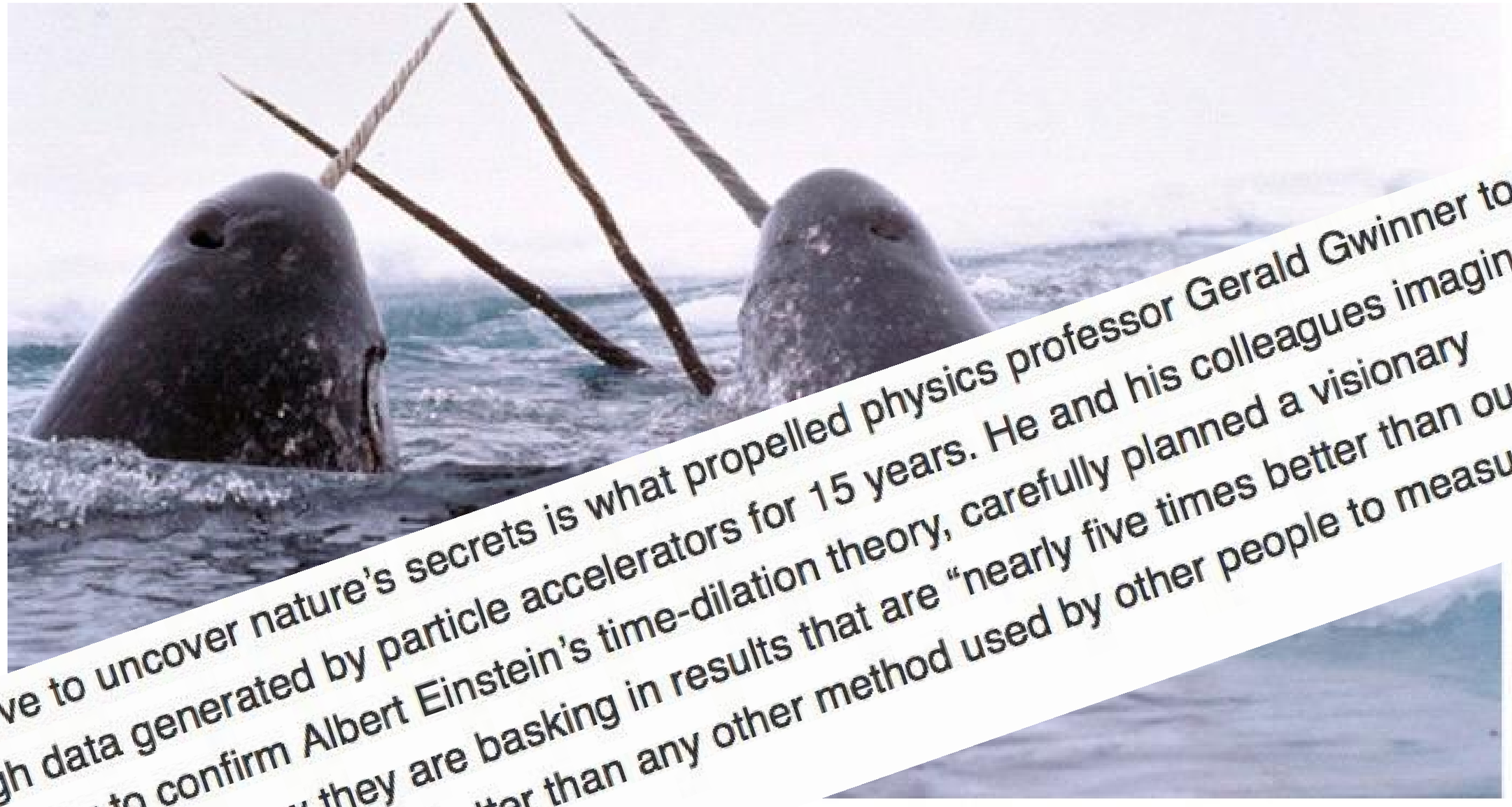
GSI Heavy Ion Research Facility, Darmstadt, Germany

What's next?

- at ESR (GSI, Darmstadt) much higher velocities attainable (> 30% c), can expect $\alpha_{\mathrm{ESR}} < 8 \times 10^{-9}$

  but ...





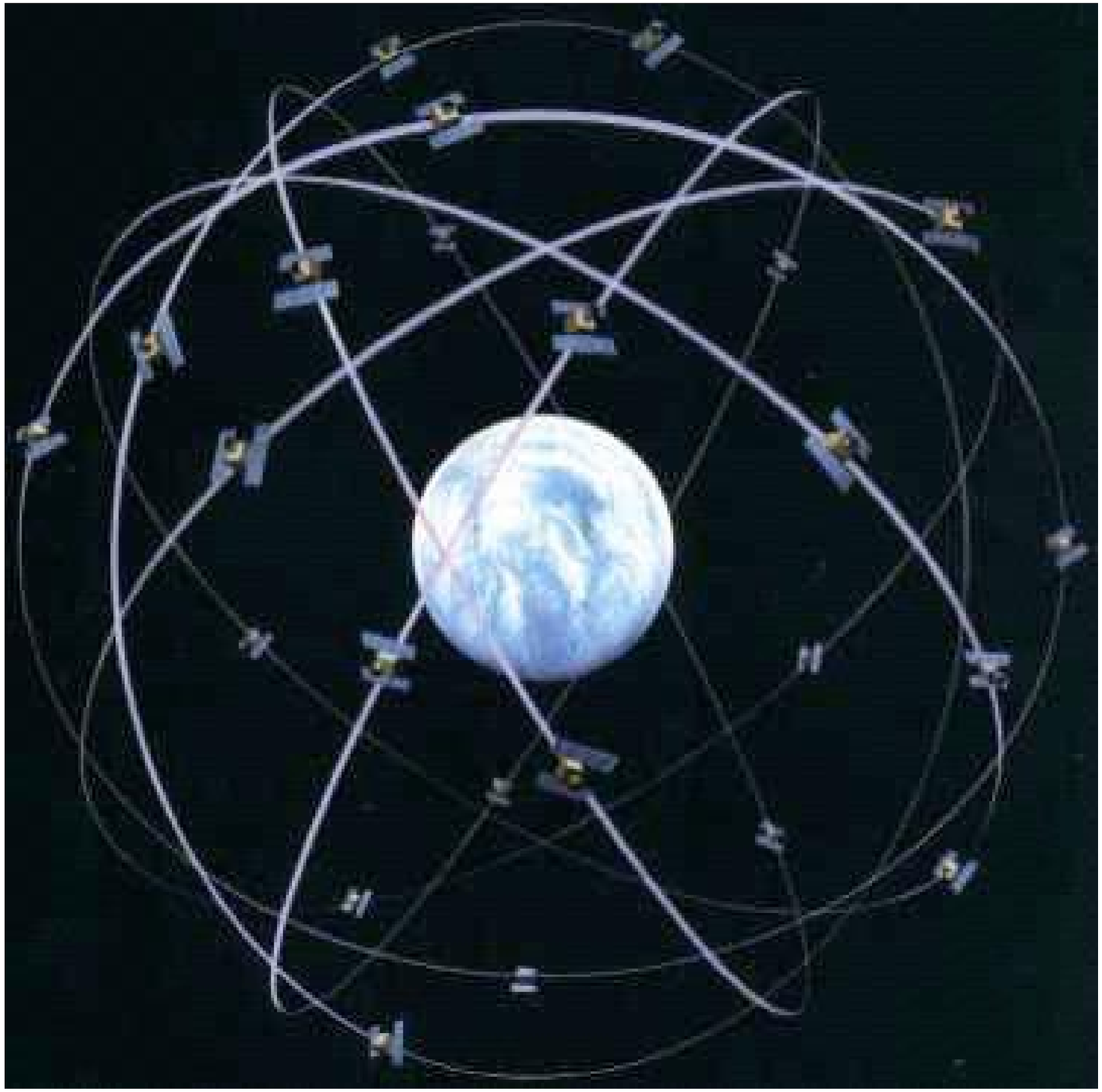
The drive to uncover nature's secrets is what propelled physics professor Gerald Gwinner to slog through data generated by particle accelerators for 15 years. He and his colleagues imagined a better way to confirm Albert Einstein's time-dilation theory, carefully planned a visionary experiment, and now they are basking in results that are "nearly five times better than our old result and 50 to 100 times better than any other method used by other people to measure relativistic time dilation."

... WILLIAMS - NATIONAL INSTITUTE OF STANDARDS AND

...o new studies: Verifying Einstein's time-dilation theory, and understanding whale testicles

SEPTEMBER 24, 2014 — University of Manitoba researchers constantly find insights into nature's

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)!

Can we understand why Lorentz invariance [sh]{c}ould break down ?

- Idea: Planck length (10^{-35} m) is a universal, smallest length in the universe
- Space-time is discrete at these length scales
- Lorentz contraction cannot be valid here, as Planck length is same in all inertial frames

$$\ell_{\mathrm{P}} = \sqrt{\frac{\hbar G}{c^3}}$$

Or: In a cosmological picture

- Special relativity

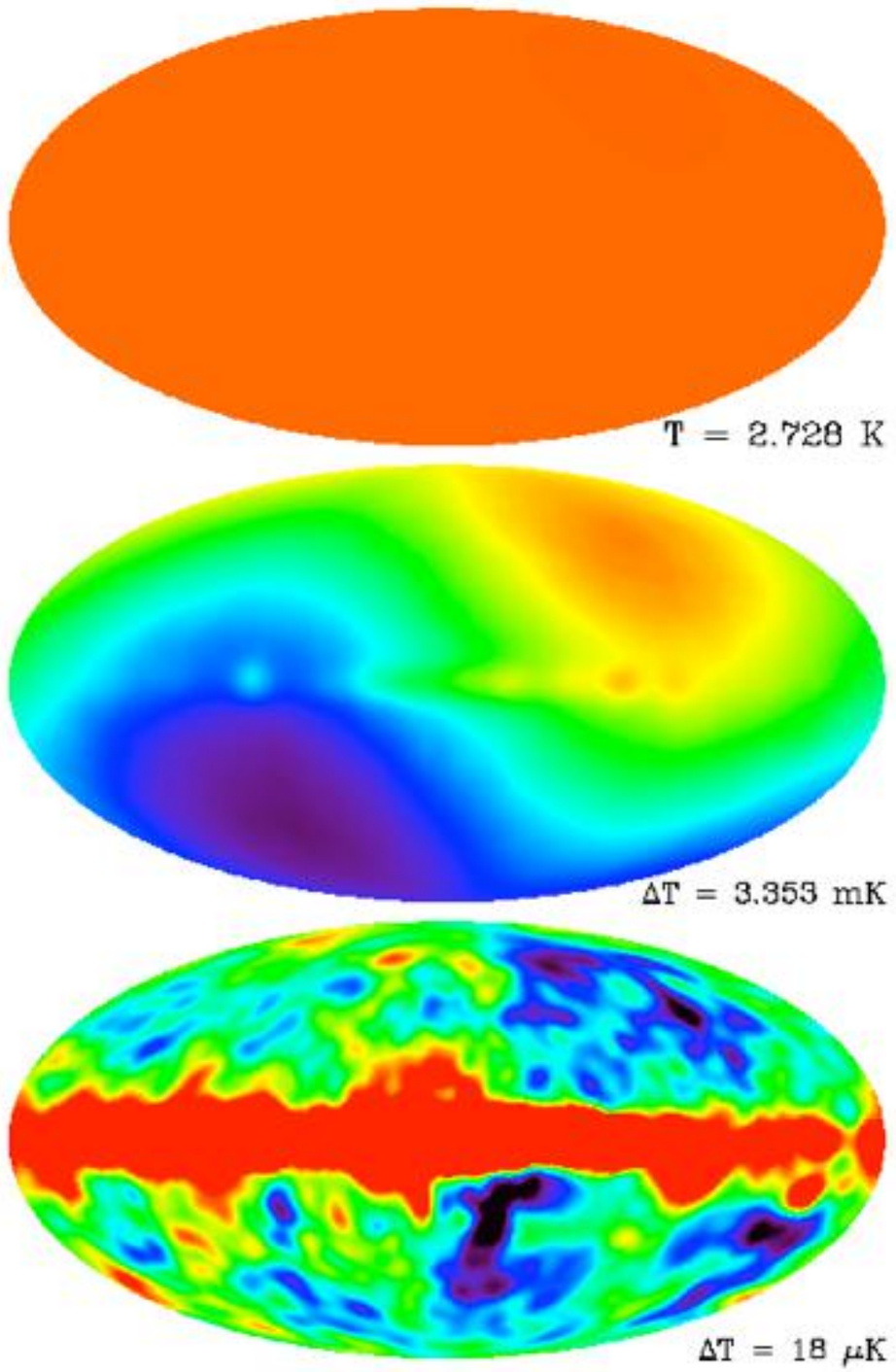
  ↕

  all inertial frames are equivalent

- SR violated

  →

  preferred frame in the universe



Thank you!

Winnipeg (“where all atoms are ultracold”)