Anisotropy of hadron universe

with the maximum attainable speed

Bogdan Wojtsekhowski, Jefferson Lab

- One-way speed without a clock
- Concept of a GF experiment

History of the measurements

1638 Galilei: at least 10 times faster than sound

"A human controlled pulse light source" – Modern day experiment!
The idea is to have two people far away from each other, with covered lanterns. One uncovers his lantern, then the other immediately uncovers his on seeing the light from the first. This routine is to be practised with the two close together, so they will get used to the reaction times involved, then they are to do it two or three miles apart, or even further using telescopes, to see if the time interval is perceptibly lengthened. Galileo tried the experiment at distances less than a mile, and couldn't detect a time lag.

History of the measurements

1638 Galilei: at least 10 times faster than sound

1675 Roemer: 200,000 km/sec (Jupiter's moons)

1728 Bradley: 301,000 km/s (Stellar aberration)

1849 Fizeau: 313,300 km/s (toothed wheel)

1862 Foucault: 299,796 km/s (rotating mirror)

Today: 299,792.458 km/s

History of the measurements

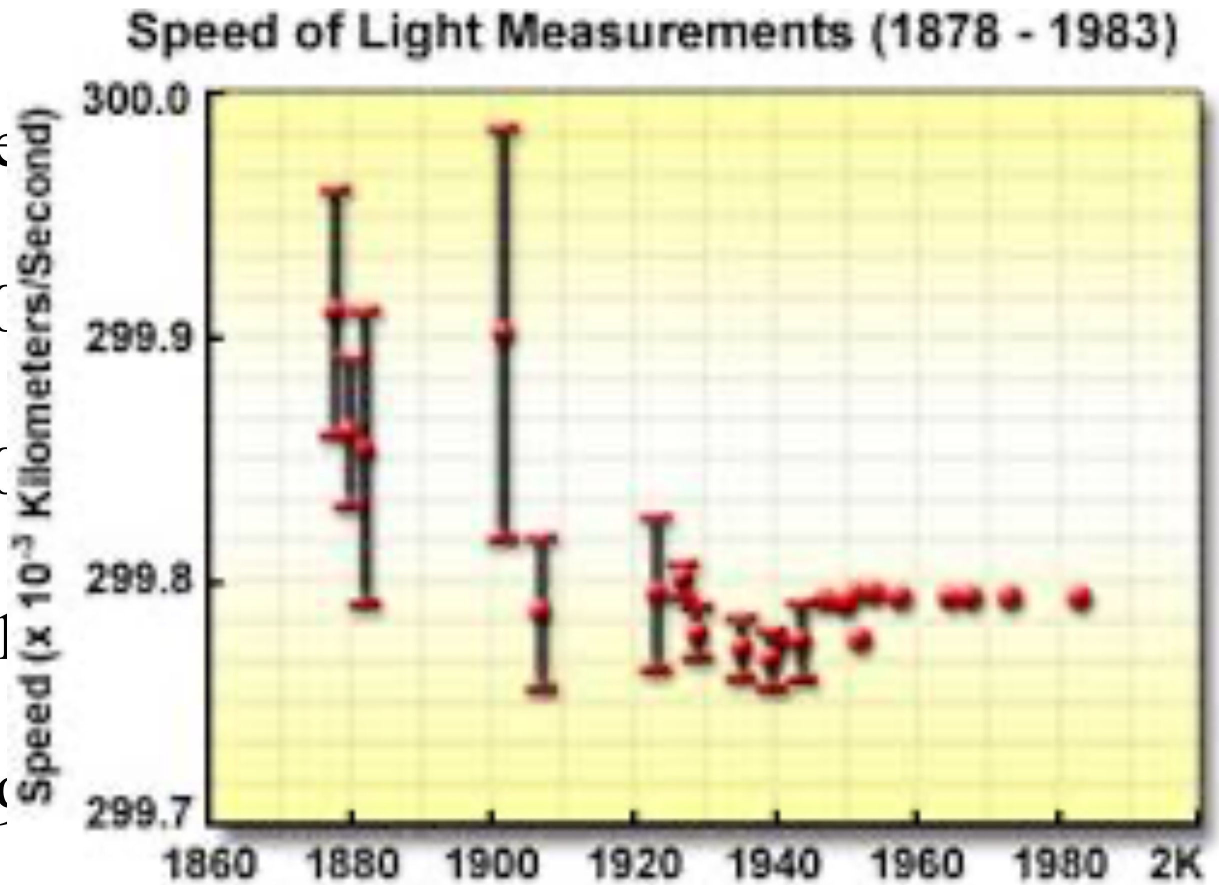
1638 Galilei: at le

1675 Roemer: 2(

1728 Bradley: 3(

1849 Fizeau: 31

1862 Foucault: 2(



Today: 299,792.458 km/s

Einstein's postulates of physics

The laws by which the states of physical systems undergo change are not affected, whether these changes of state be referred to the one or the other of two systems of coordinates in uniform translatory motion.

Any ray of light moves in the "stationary" system of coordinates with determined velocity ***c***, whether the ray be emitted by a stationary or by a moving body.

Einstein, Ann. d. Physik ***17*** *(1905)*

The speed measurement

The speed of light is said to be *isotropic* if it has the same value when measured in any/every direction.

The constancy of the one-way speed in any given inertial frame is the basis of the special theory of relativity.

How do we measure the speed?

one-way: $v_1 = d_{AB}/t_{AB}$

The speed measurement

The speed of light is said to be *isotropic* if it has the same value when measured in any/every direction.
The constancy of the one-way speed in any given inertial frame is the basis of the special theory of relativity.

How do we measure the speed?

one-way: $v_1 = d_{AB}/t_{AB}$

Require high precision synchronized clocks

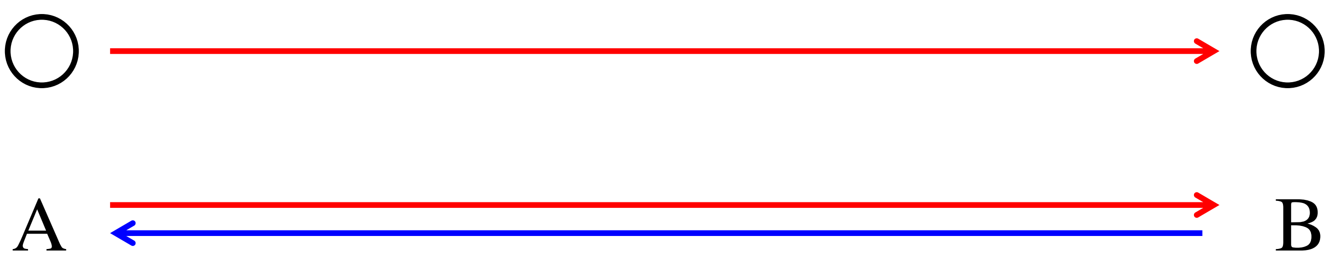
The speed measurement

The speed of light is said to be *isotropic* if it has the same value when measured in any/every direction.

The constancy of the one-way speed in any given inertial frame is the basis of the special theory of relativity.

How do we measure the speed?

one-way: $v_1 = d_{AB}/t_{AB}$

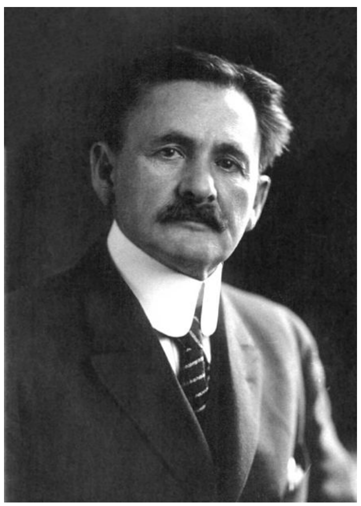


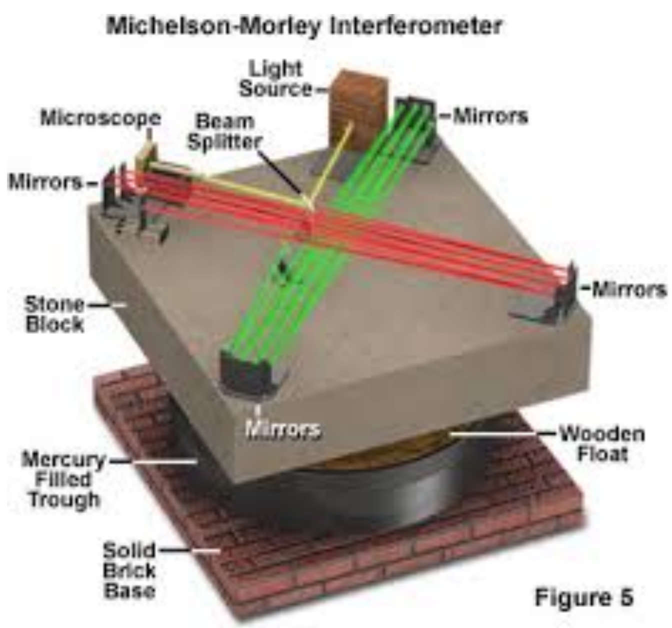
Two-way (round-trip):

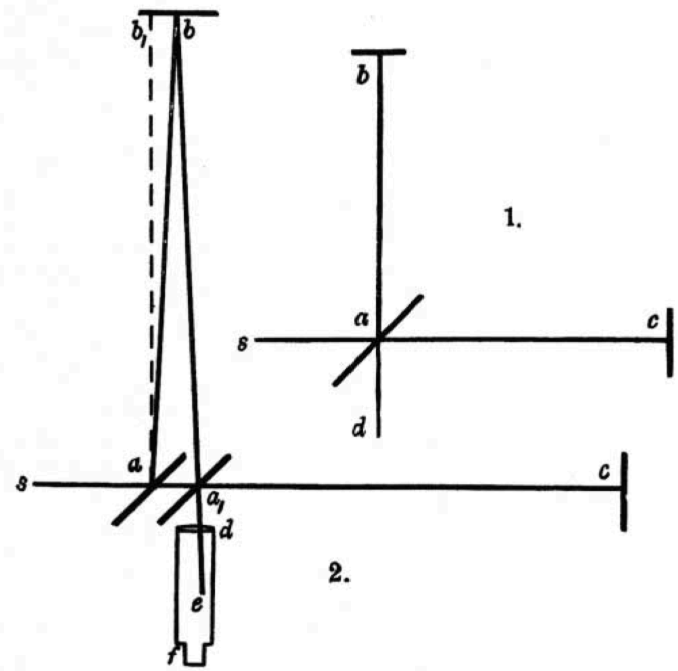
$v_2 = (d_{AB}+d_{BA})/(t_{AB}+t_{AB})$

Michelson-Morley experiment

The speed of light is said to be *isotropic* if it has the same value when measured in any/every direction.





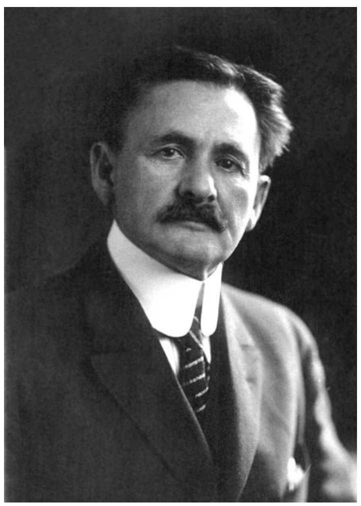


accuracy scale: 1μm / 10m ~ 10^{-7}

Michelson-Morley experiment

The speed of light is said to be *isotropic* if it has the same value when measured in any/every direction.

Michelson and Morley—Relative Motion of the **341**



displacement should be $2D\frac{v^2}{V^2}=2D\times$ 10^{-8} The distance D was about eleven meters, or 2×10^7 wave-lengths of yellow light; hence the displacement to be expected was 0·4 fringe. The actual displacement was certainly less than the twentieth part of this, and probably < 1/14 of the predicted value But since the displacement is proportional to the square of the velocity, the relative velocity of the earth and the ether is probably less than one sixth the earth's orbital velocity, and certainly less than one-fourth.

In what precedes, only the orbital motion of the earth is con- ...ined with the motion of the solar sys- tem, concerning which but little is known with certainty, the

$\frac{\Delta c}{c} < 10^{-5}$ for two-way speed

Tests of Lorentz Invariance

- Two-way speed via rotating cavities: $\Delta c_2/c < 10^{-18\ (20)}$
- One-way speed via asymmetric optical ring: $\Delta c_1/c < 10^{-14}$
- One-way speed via e^+e^- beam orbit shape: $\Delta c_1/c < 5{\times}10^{-15}$
  (PRD 101, 032004 (2020))

These are for a photon and an electron

Tests of Lorentz Invariance

$$c_p - c_\gamma < 1 \times 10^{-23}$$

$$|c_m - c_\gamma| < 6 \times 10^{-22}$$

$$|c' - c|_{\nu_e \nu_\mu} < 6 \times 10^{-22}$$

$$|c' - c|_{\mu e} < 4 \times 10^{-21}$$

$$|c_{K_L} - c_{K_S}| < 3 \times 10^{-21}$$

These are astrophysics based limits for two-way MAS of the hadrons and mesons obtained by Coleman & Glashow in PRD 59, 116008 (1999) from the analysis of particle decays

The framework (mSME) originated by V.A. Kostelecky and collaborators, Phys. Rev. Lett. 87, 251304 (2001); Phys. Rev. D 66, 056005 (2002) ++

Tests of Lorentz Invariance

At what level could we expect a Lorentz Invariance violation?

$$E^2 = m^2 + p^2 + \boxed{E_{\mathrm{Pl}} f_i^{(1)} p^i} + f_{ij}^{(2)} p^i p^j + \frac{f_{ijk}^{(3)}}{E_{\mathrm{Pl}}} p^i p^j p^k + \dots ,$$

dispersion equation in some LI violation models
see, Mattingly, Living Rev. Rel. 8 (2005) 5

One-way speed without a clock

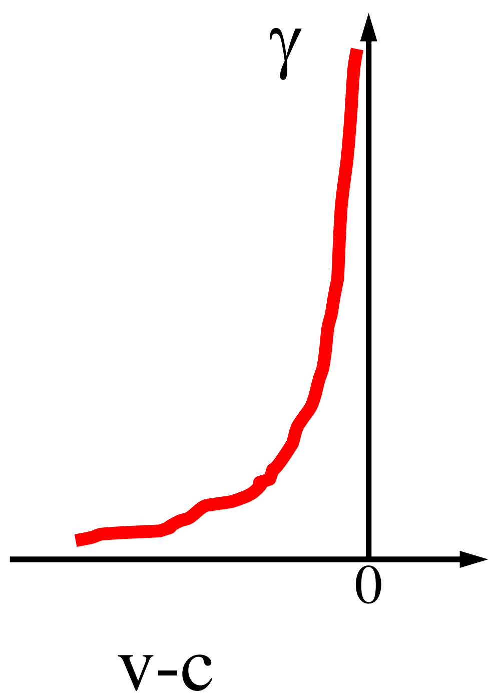
One can compare the speeds of light quanta of different energies – this was done using astrophysics data from distant objects.

One can measure directly the relative speed of a massive particle and light quanta. This could be done with high but still limited accuracy: $(v-c)/c \sim 10^{-3}$.

Let us use a Lorentz factor γ as a measure of the $(v-c)$ because the value of γ is very sensitive to $(v-c)$ for high energy particles and variation of the γ as a particle's momentum turns around.

Speed of light variation and Lorentz factor

$$\gamma = \frac{c}{\sqrt{(c-v)\cdot(c+v)}}$$



When the value of the speed $\boldsymbol{v}$ is fixed, a tiny variation of **c** in the direction of motion leads to a large variation of **γ**, which provides a powerful enhancement of sensitivity to a possible variation of **c**.

$$\frac{\Delta\gamma}{\gamma} = \gamma^2 \cdot \frac{\Delta c}{c}$$

Special relativity experiment at GF

- LI test for nuclei, directional variation of the maximum attainable speed (MAS).
- Narrow energy band and huge intensity lead to great accuracy for the beam Lorentz factor $\gamma_{+/-} = \gamma_2$, GF photon beam is a great tool for testing a two-way MAS, as was done in γ-e Compton for electron: PRL 104, 241601 (2010).

The photon energy total gain factor of $4\gamma_2^2$ is the result of two boosts in opposite directions, so $\gamma_2^2 = \gamma_{ab} * \gamma_{ba}$ which corresponds to a two-way maximum attainable speed.
Grenoble's experiment detected the electrons and measure the Compton edge – maximum energy loss, which is prop. to γ_2^2

Special relativity experiment at GF

- LI test for nuclei, directional variation of the maximum attainable speed (MAS).
- Narrow energy band and huge intensity lead to great accuracy for the beam Lorentz factor $\gamma_{+/-} = \gamma_2$, GF photon beam is a great tool for testing a two-way MAS, as was done in γ-e Compton for electron: PRL 104, 241601 (2010).

At GF the same could be done for the hadrons.

$$\lambda' \simeq \tilde{\lambda}_{\mathrm{CE}} + 0.91 \frac{2\gamma^2 \lambda_{\mathrm{CE}}}{(1 + 4\gamma\lambda/m)^2} \sqrt{\kappa_X^2 + \kappa_Y^2} \sin\Omega t.$$

Special relativity experiment at GF

- LI test for nuclei, directional variation of the maximum attainable speed (MAS).
- Narrow energy band and huge intensity lead to great accuracy for the beam Lorentz factor $\gamma_{+/-} = \gamma_2$, GF photon beam is a great tool for testing a two-way MAS, as was done in γ-e Compton for electron: PRL 104, 241601 (2010).
- Narrow energy band and huge intensity lead to great accuracy for the LI test of a time dilation factor , as it was done in Li+ ion : PRL 113, 120405 (2014). It is the test for a two-way MAS.

At GF the same could be done for much higher Lorentz factor.

$$\frac{\nu_a \nu_p}{\nu_1 \nu_2} = \frac{1}{\gamma^2(1-\beta^2)} = 1,$$

Special relativity experiment at GF

- LI test for nuclei, directional variation of the maximum attainable speed (MAS).
- Narrow energy band and huge intensity lead to great accuracy for the beam Lorentz factor $\gamma_{+/-} = \gamma_2$. GF is a great tool for testing a two-way MAS: PRL 104, 241601 (2010), PRL 113, 120405 (2014).
- Two beams lead to cancelation of the ring orbit deformations (tide) and magnetic force/orbit shape variation (for LHC discussed with J. Wenninger) allows to access a nuclei one-way MAS via γ_1, similar to the experiment for e+/e-, see PRD 101, 032004 (2020).

This method requires high accuracy/stability beam position monitors

$$\Delta x^*_{\pm} = \eta^{-1}(s) \times a_{\perp} \times [\cos(\Omega \cdot t - \Phi) * \cos(\Psi(s)) +$$

$$+ \sin(\theta_{CESR}) * \sin(\Omega \cdot t - \Phi) * \sin(\Psi(s))] + \Delta x^{ref}_{\pm} .$$

Special relativity experiment at GF

- Two beams lead to cancelation of the ring orbit deformations (tide) and magnetic force/orbit shape variation (for LHC discussed with J. Wenninger) allows to access a nuclei one-way MAS via γ_1, similar to the experiment for e+/e-, see PRD 101, 032004 (2020).

- Photon beam allows study of one-way MAS via a two-step emission process: 1s->3p->2s->1s. The last transition will provide the photon beam which energy is sensitive to one-way MAS.
  The intermediate transition erases memory of the excitation step.

Special relativity experiment at GF

- Two beams lead to cancelation of the ring orbit deformations (tide) and magnetic force/orbit shape variation (for LHC discussed with J. Wenninger) allows to access a nuclei one-way MAS via γ_1, similar to the experiment for e+/e-, see PRD 101, 032004 (2020).

- Photon beam allows study of one-way MAS via a two-step emission process: 1s->3p->2s->1s. The last transition will provide the photon beam which energy is sensitive to one-way MAS.
  The intermediate transition erases memory of the excitation step.

Even more interesting: let us use two lines 3p->2s and 2s->1s
The first is sensitive to γ_2 and second for γ_1, the difference should be almost systematic "free" investigation of the hadron one-way MAS.

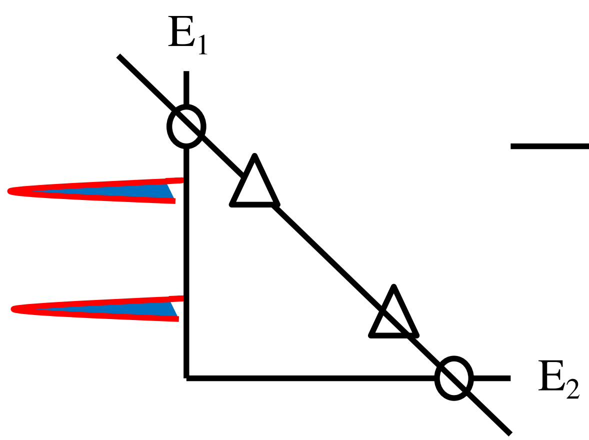
.

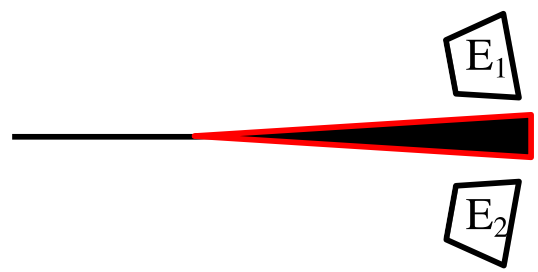
Special relativity experiment at GF

- LI test for nuclei, directional variation of the maximum attainable speed (MAS).
- Photon beam allows study of one-way MAS via a two-step emission process: 1s->3p->2s->1s. The last transition will provide the photon beam which energy is sensitive to one-way MAS.

The intermediate transition erases memory of the excitation step.

Detecting the final photons can be done e.g. by means of a magnetic e+e- pair spectrometer or with a double crystal setup:





Special relativity experiment at GF

- LI test for nuclei, directional variation of the maximum attainable speed (MAS).
- Narrow energy band and huge intensity lead to great accuracy for the beam Lorentz factor $\gamma_{+/-} = \gamma_2$. GF is a great tool for testing a two-way MAS: PRL 104, 241601 (2010), PRL 113, 120405 (2014).
- Two beams lead to cancelation of the ring orbit deformations (tide) and magnetic force/orbit shape variation (for LHC discussed with J. Wenninger) allows to access a nuclei one-way MAS via γ_1, similar to the experiment for e+/e-, see PRD 101, 032004 (2020).
- Photon beam allows study of one-way MAS via a two-step emission process: 1s->3p->2s->1s. The last transition will provide the photon beam which energy is sensitive to one-way MAS.

- Variation of MAS on the level of 10^{-14} can be observed in an hour.

Summary

- A search for LIV anisotropy of the maximum attainable speed of a hadron is proposed – requires precision monitoring of the sidereal time variation of the photon beam energy.
- The Gamma Factory parameters are unique – large Lorentz factor, two beams and huge photon beam intensity with a tiny energy spread. GF is the place to do LIV experiment.
- Achievable accuracy for hadron MAS LIV is better than 10^{-14}