On Measurement of the Isotropy of the Maximum Attainable Speed

Bogdan Wojtsekhowski, Jefferson Lab

- Motivation
- Experimental tests of Lorentz invariance
- A new proposal

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)*

Experimental tests

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

Postulates:

1. 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.
2. 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.

A concept of the speed of light

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

One-way speed and two-way speed: What is the difference?

What is experimentally investigated most often is
a **round-trip speed**
(or "**two-way" speed of light**)
from the source to the detector and back again.

Experimental tests

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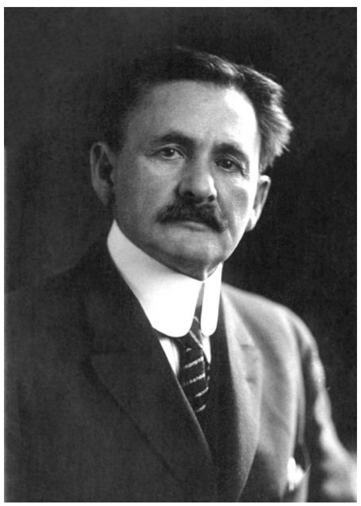
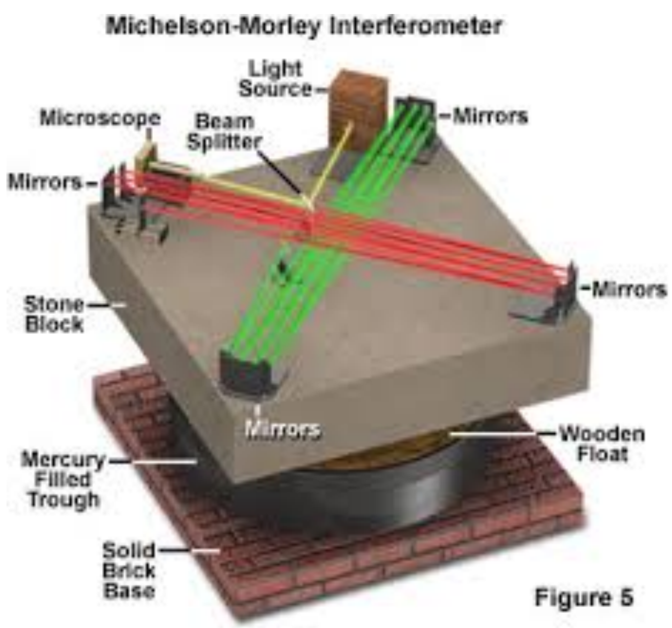
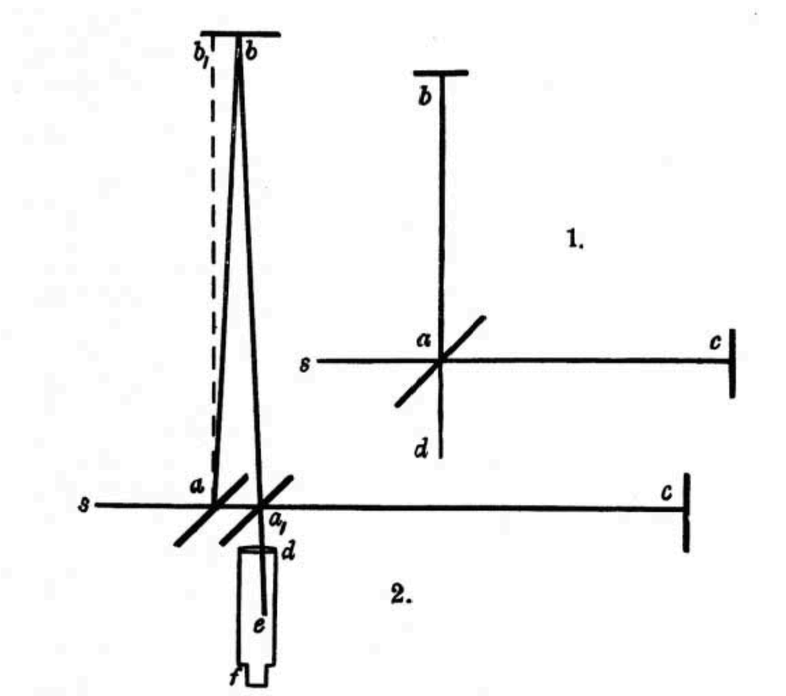
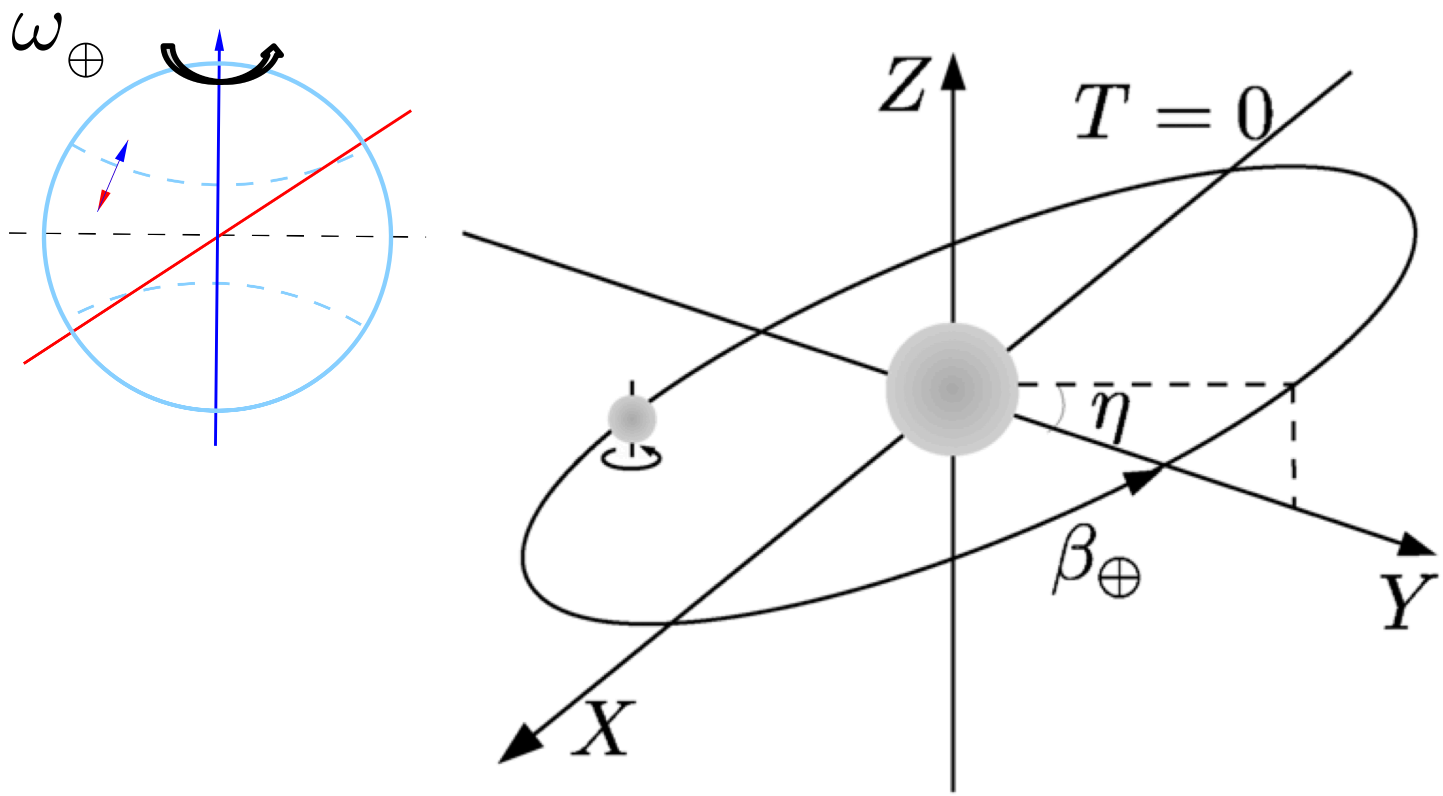






Coordinate system



Experimental tests

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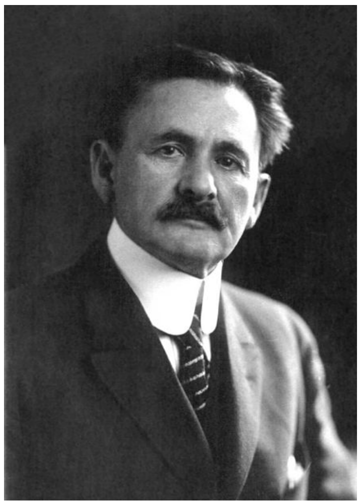

Noon Observations.

	16.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.
July 8	44·7	44·0	43·5	39·7	35·2	34·7	34·3	32·5	28·2	26·2	23·8	23·2	20·3	18·7	17·5	16·8	13·7
July 9	57·4	57·3	58·2	59·2	58·7	60·2	60·8	62·0	61·5	63·3	65·8	67·3	69·7	70·7	73·0	70·2	72·2
July 11	27·3	23·5	22·0	19·3	19·2	19·3	18·7	18·8	16·2	14·3	13·3	12·8	13·3	12·3	10·2	7·3	6·5
Mean	43·1	41·6	41·2	39·4	37·7	38·1	37·9	37·8	35·3	34·6	34·3	34·4	34·4	33·9	33·6	31·4	30·8
Mean in w. l.	·862	·832	·824	·788	·754	·762	·758	·756	·706	·692	·686	·688	·688	·678	·672	·628	·616
	·706	·692	·686	·688	·688	·678	·672	·628	·616								
Final mean.	·784	·762	·755	·738	·721	·720	·715	·692	·661								

P. M. Observations.

July 8	61·2	63·3	63·3	68·2	67·7	69·3	70·3	69·8	69·0	71·3	71·3	70·5	71·2	71·2	70·5	72·5	75·7
July 9	26·0	26·0	28·2	29·2	31·5	32·0	31·3	31·7	33·0	35·8	36·5	37·3	38·8	41·0	42·7	43·7	44·0
July 12	66·8	66·5	66·0	64·3	62·2	61·0	61·3	59·7	58·2	55·7	53·7	54·7	55·0	58·2	58·5	57·0	56·0
Mean	51·3	51·9	52·5	53·9	53·8	54·1	54·3	53·7	53·4	54·3	53·8	54·2	55·0	56·8	57·2	57·7	58·6
Mean in w. l.	1·026	1·038	1·050	1·078	1·076	1·082	1·086	1·074	1·068	1·086	1·076	1·084	1·100	1·136	1·144	1·154	1·172
	1·068	1·086	1·076	1·084	1·100	1·136	1·144	1·154	1·172								
Final mean.	1·047	1·062	1·063	1·081	1·088	1·109	1·115	1·114	1·120								

Experimental tests

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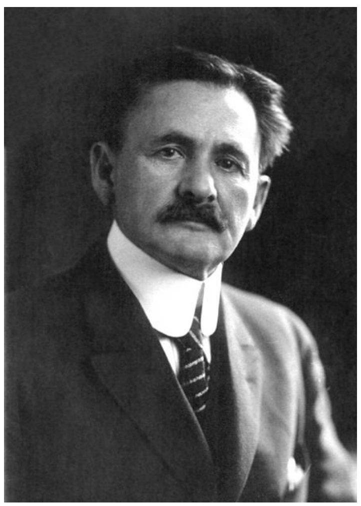
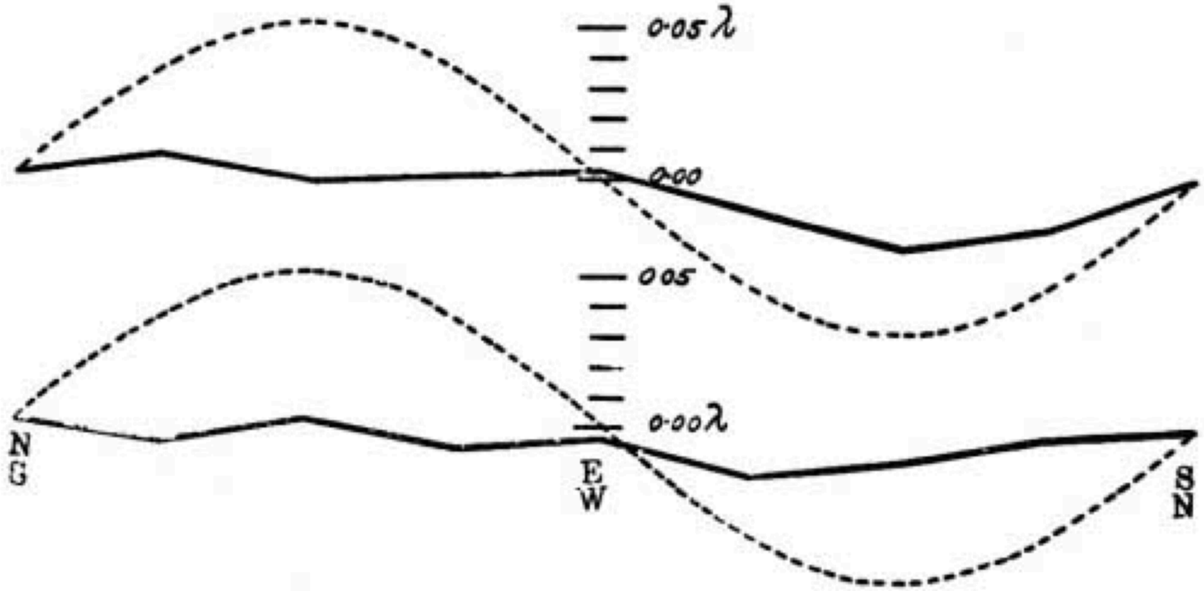


The results of the observations are expressed graphically in fig. 6. The upper is the curve for the observations at noon, and the lower that for the evening observations. The dotted curves represent *one-eighth* of the theoretical displacements. It seems fair to conclude from the figure that if there is any dis-

6.



placement due to the relative motion of the earth and the luminiferous ether, this cannot be much greater than 0·01 of the distance between the fringes.

Experimental tests

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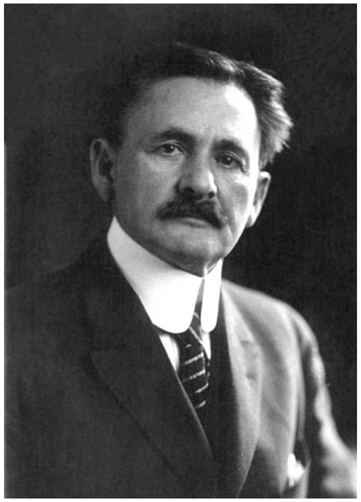

Michelson and Morley—Relative Motion of the 341

displacement should be $2D\frac{v^2}{V^2}=2D\times10^{-8}$. 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 less than the fortieth part. 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 considered. If this is combined with the motion of the solar system, concerning which but little is known with certainty, the

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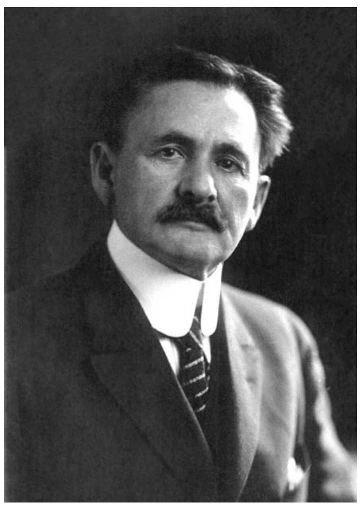

displacement should be $2D\frac{v^2}{V^2} = 2D \times 10^{-8}$. The distance D was about eleven meters, or 2×10^7 wave-lengths of yellow light; hence the displacement to be expected was 0·4 fringe. The actual displacement was certainly less than the twentieth part of this, and probabl

< 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

Recent experiments

PRL **113**, 120405 (2014) PHYSICAL REVIEW LETTERS week ending 19 SEPTEMBER 2014

Test of Time Dilation Using Stored Li^+ Ions as Clocks at Relativistic Speed

Benjamin Botermann,[1] Dennis Bing,[2] Christopher Geppert,[1,3,4] Gerald Gwinner,[5] Theodor W. Hänsch,[6] Gerhard Huber,[7] Sergei Karpuk,[7] Andreas Krieger,[1] Thomas Kühl,[3] Wilfried Nörtershäuser,[1,3,8] Christian Novotny,[4] Sascha Reinhardt,[6] Rodolfo Sánchez,[4] Dirk Schwalm,[2] Thomas Stöhlker,[3] Andreas Wolf,[2] and Guido Saathoff[6]

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[6]*Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany*
[7]*Johannes Gutenberg-Universität Mainz, Institut für Physik, 55128 Mainz, Germany*
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We present the concluding result from an Ives-Stilwell-type time dilation experiment using $^7Li^+$ ions confined at a velocity of $\beta = v/c = 0.338$ in the storage ring ESR at Darmstadt. A Λ-type three-level system within the hyperfine structure of the $^7Li^{+\,3}S_1 \rightarrow {}^3P_2$ line is driven by two laser beams aligned parallel and antiparallel relative to the ion beam. The lasers' Doppler shifted frequencies required for resonance are measured with an accuracy of $< 4 \times 10^{-9}$ using optical-optical double resonance spectroscopy. This allows us to verify the special relativity relation between the time dilation factor γ and the velocity β, $\gamma\sqrt{1-\beta^2} = 1$ to within $\pm 2.3 \times 10^{-9}$ at this velocity. The result, which is singled out by a high boost velocity β, is also interpreted within Lorentz invariance violating test theories.

Recent experiments

Direct Terrestrial Measurement of the Spatial Isotropy of the Speed of Light to 10^{-18}

Moritz Nagel[1], Stephen R. Parker[2,*], Evgeny V. Kovalchuk[1], Paul L. Stanwix[2], John G. Hartnett[2,3], Eugene N. Ivanov[2], Achim Peters[1], and Michael E. Tobar[2]

Lorentz symmetry is a foundational property of modern physics, underlying both the standard model of particles and general relativity. It is anticipated that these two theories are merely low energy approximations of a single theory of the four fundamental forces that is unified and consistent at the Planck scale [1]. Many unifying proposals allow for Lorentz symmetry to be broken, with observable effects appearing at Planck-suppressed levels [2]. Thus precision tests of Lorentz Invariance Violation (LIV) are needed to assess and guide theoretical efforts. The most significant consequence of Lorentz symmetry is the isotropic nature of the speed of light, which remains invariant under rotation and boost transformations. In this work we use two ultra-stable oscillator frequency sources [3] to perform a modern Michelson-Morley experiment [4] and make the most precise measurement to date of the spatial isotropy of the speed of light, constraining $\Delta c/c$ to $9.2\pm10.7\times10^{-19}$ (95%C.I.). This order of magnitude improvement over the current state-of-the-art allows us to undertake the first terrestrial test of LIV in electrodynamics at the Planck-suppressed electroweak unification scale [5], finding no significant violation of Lorentz symmetry.

Recent experiments

PRL **110,** 200401 (2013) PHYSICAL REVIEW LETTERS week ending 17 MAY 2013

New Limit on Lorentz Violation Using a Double-Pass Optical Ring Cavity

Yuta Michimura,[1,*] Nobuyuki Matsumoto,[1] Noriaki Ohmae,[2] Wataru Kokuyama,[3]
Yoichi Aso,[1] Masaki Ando,[4] and Kimio Tsubono[1]

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(Received 18 December 2012; published 13 May 2013)

A search for Lorentz violation in electrodynamics was performed by measuring the resonant frequency difference between two counterpropagating directions of an optical ring cavity. Our cavity contains a dielectric element, which makes our cavity sensitive to the violation. The laser frequency is stabilized to the counterclockwise resonance of the cavity, and the transmitted light is reflected back into the cavity for resonant frequency comparison with the clockwise resonance. This double-pass configuration enables a null experiment and gives high common mode rejection of environmental disturbances. We found no evidence for odd-parity anisotropy at the level of $\delta c/c \lesssim 10^{-14}$. Within the framework of the standard model extension, our result put more than 5 times better limits on three odd-parity parameters $\tilde{\kappa}_{o+}^{JK}$ and a 12 times better limit on the scalar parameter $\tilde{\kappa}_{\mathrm{tr}}$ compared with the previous best limits.

Recent experiments

PRL **104,** 241601 (2010) PHYSICAL REVIEW LETTERS week ending 18 JUNE 2010

Limits on Light-Speed Anisotropies from Compton Scattering of High-Energy Electrons

J.-P. Bocquet,[1] D. Moricciani,[2] V. Bellini,[3] M. Beretta,[4] L. Casano,[2] A. D'Angelo,[5] R. Di Salvo,[2] A. Fantini,[5] D. Franco,[5] G. Gervino,[6] F. Ghio,[7] G. Giardina,[8] B. Girolami,[7] A. Giusa,[3] V. G. Gurzadyan,[9,10] A. Kashin,[9] S. Knyazyan,[9] A. Lapik,[11] R. Lehnert,[12,*] P. Levi Sandri,[4] A. Lleres,[1] F. Mammoliti,[3] G. Mandaglio,[8] M. Manganaro,[8] A. Margarian,[9] S. Mehrabyan,[9] R. Messi,[5] V. Nedorezov,[11] C. Perrin,[1] C. Randieri,[3] D. Rebreyend,[1,†] N. Rudnev,[11] G. Russo,[3] C. Schaerf,[5] M. L. Sperduto,[3] M. C. Sutera,[3] A. Turinge,[11] and V. Vegna[5]

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[4]*INFN Laboratori Nazionali di Frascati, 00044 Frascati, Italy*
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[9]*Yerevan Physics Institute, 375036 Yerevan, Armenia*
[10]*Yerevan State University, 375025 Yerevan, Armenia*
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(Received 22 February 2010; published 17 June 2010)

The possibility of anisotropies in the speed of light relative to the limiting speed of electrons is considered. The absence of sidereal variations in the energy of Compton-edge photons at the European Synchrotron Radiation Facility's GRAAL facility constrains such anisotropies representing the first nonthreshold collision-kinematics study of Lorentz violation. When interpreted within the minimal standard-model extension, this result yields the two-sided limit of $\boxed{1.6 \times 10^{-14} \text{ at } 95\%}$ confidence level on a combination of the parity-violating photon and electron coefficients $(\tilde{\kappa}_{o+})^{YZ}$, $(\tilde{\kappa}_{o+})^{ZX}$, c_{TX}, and c_{TY}. This new constraint provides an improvement over previous bounds by 1 order of magnitude.

Recent experiments

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PRL **104,** 241601 (2010) PHYSICAL REV

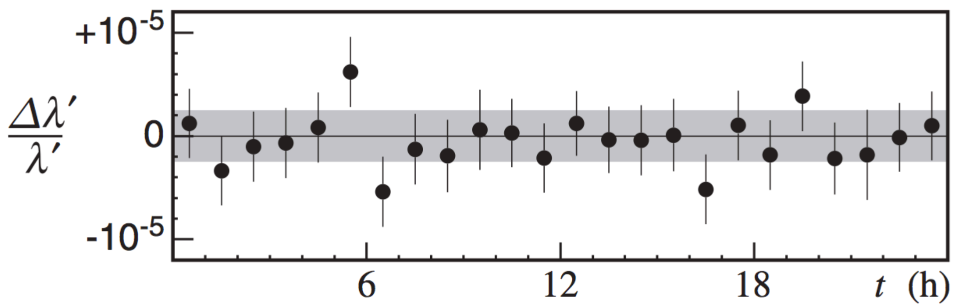

FIG. 4. Full set of data folded modulo a sidereal day (24 bins). The error bars are purely statistical and agree with the dispersion of the data points ($\chi^2 = 1.04$ for the unbinned histogram). The shaded area corresponds to the region of nonexcluded signal amplitudes.

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$$\frac{\Delta x_{\mathrm{CE}}}{x_{\mathrm{CE}}} = \frac{p}{p - \lambda_{\mathrm{CE}}} \frac{\Delta\lambda'}{\lambda'}. \qquad (7)$$

This new constraint provides an improvement over previous bounds by 1 order of magnitude.

Recent experiments

Author	Year	RMS		SME		
		Orientation	Velocity	$\tilde{\kappa}_{e-}$	$\tilde{\kappa}_{o+}$	$\tilde{\kappa}_{tr}$
Michimura *et al.*[20]	2013				$0.7\pm1\times10^{-14}$	$-0.4\pm0.9\times10^{-10}$
Baynes *et al.*[21]	2012					$3\pm11\times10^{-10}$
Baynes *et al.*[22]	2011				$0.7\pm1.4\times10^{-12}$	$3.4\pm6.2\times10^{-9}$
Hohensee *et al.*[13]	2010			$0.8(0.6)\times10^{-16}$	$-1.5(1.2)\times10^{-12}$	$-1.5(0.74)\times10^{-8}$
Bocquet *et al.*[16]	2010				$\lesssim1.6\times10^{-14}$ [23]	
Herrmann *et al.*[24]	2009	$(4\pm8)\times10^{-12}$		$(-0.31\pm0.73)\times10^{-17}$	$(-0.14\pm0.78)\times10^{-13}$	
Eisele *et al.*[25]	2009	$(-1.6\pm6\pm1.2)\times10^{-12}$		$(0.0\pm1.0\pm0.3)\times10^{-17}$	$(1.5\pm1.5\pm0.2)\times10^{-13}$	
Tobar *et al.*[26]	2009		$-4,8(3,7)\times10^{-8}$			
Tobar *et al.*[27]	2009					$-0.3\pm3\times10^{-7}$
Müller *et al.*[28]	2007			$(7.7(4.0))\times10^{-16}$	$(1.7(2.0))\times10^{-12}$	
Carone *et al.*[29]	2006					$\lesssim3\times10^{-8}$ [30]
Stanwix *et al.*[31]	2006	$9.4(8.1)\times10^{-11}$		$(-6.9(2.2))\times10^{-16}$	$(-0.9(2.6))\times10^{-12}$	
Herrmann *et al.*[32]	2005	$(-2.1\pm1.9)\times10^{-10}$		$(-3.1(2.5))\times10^{-16}$	$(-2.5(5.1))\times10^{-12}$	
Stanwix *et al.*[33]	2005	$-0.9(2.0)\times10^{-10}$		$(-0.63(0.43))\times10^{-15}$	$(0.20(0.21))\times10^{-11}$	
Antonini *et al.*[34]	2005	$(+0.5\pm3\pm0.7)\times10^{-10}$		$(-2\pm0,2)\times10^{-14}$		
Wolf *et al.*[35]	2004			$(-5.7\pm2.3)\times10^{-15}$	$(-1.8\pm1.5)\times10^{-11}$	
Wolf *et al.*[36]	2004	$(+1.2\pm2.2)\times10^{-9}$	$(3.7\pm3.0)\times10^{-7}$			
Müller *et al.*[37]	2003	$(+2.2\pm1.5)\times10^{-9}$		$(1.7\pm2.6)\times10^{-15}$	$(14\pm14)\times10^{-11}$	
Lipa *et al.*[38]	2003			$(1.4\pm1.4\times10^{-13}$	$\lesssim10^{-9}$	
Wolf *et al.*[39]	2003	$(+1.5\pm4.2)\times10^{-9}$				
Braxmaier *et al.*[40]	2002		$(1.9\pm2.1)\times10^{-5}$			
Hils and Hall[41]	1990		6.6×10^{-5}			
Brillet and Hall[42]	1979	$\lesssim5\times10^{-9}$		$\lesssim10^{-15}$		

Tests of Lorentz Invariance

- Two-way speed via cavities: $\Delta c/c < 10^{-18}$
- Doppler effect via atomic beam, ion storage ring

- One-way speed via asymmetric optical ring (2015)
- One-way speed via laser-backscattering (2010)

$$\Delta c/c < 10^{-14}$$

At what level could we expect a LI violation?

Tests of Lorentz Invariance

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At what level could we expect a LI violation?

$$M_z / M_{Pl} \sim 10^{-17}$$

Theory of LI violation framework

PHYSICAL REVIEW D VOLUME 39, NUMBER 2 15 JANUARY 1989

Spontaneous breaking of Lorentz symmetry in string theory

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Stuart Samuel
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(Received 27 June 1988)

The possibility of spontaneous breakdown of Lorentz symmetry in string theory is explored via covariant string field theory. A potential mechanism is suggested for the Lorentz breaking that may be generic in many string theories.

The basic bosonic string has a highly constrained structure that for consistency requires a 26-dimensional spacetime. Similarly, the superstring requires ten dimensions. A dramatic metamorphosis must therefore take place if strings are to describe a world with four flat dimensions. One appealing idea is that the extra dimensions compactify. For this to happen, the 26- or 10-dimensional Poincaré symmetry must be broken. In most approaches, the occurrence of compactification must be assumed because there is no known mechanism for the breaking.

In this paper we investigate the possibility that Lorentz-symmetry breakdown is natural when the perturbative string vacuum is unstable. We present a potential mechanism for the breaking that may be generic in many string theories.

The basic idea is that Lorentz invariance can be spontaneously broken by the generation for Lorentz tensors of

its mass squared, the naive perturbative vacuum is unstable. These are three possibilities: $\langle \phi \rangle$ is infinite and the theory is ill defined; $\langle \phi \rangle$ is nonzero and positive; or $\langle \phi \rangle$ is nonzero and negative. Below, we suggest that in the latter case the coefficient of the quadratic term for the massless vector field $A^{\mu}(x)$ in the potential becomes nonzero and negative, whereupon Lorentz-symmetry breakdown takes place.

The expectation $\langle \phi \rangle$ is difficult to calculate even at the tree level. The minimum of the static effective potential $V(\phi)$ for ϕ must be found. Since at the tree level $V(\phi)$ receives equally important contributions to all orders in the coupling and no systematic truncation is known, its derivation requires knowledge of the arbitrary n-point off-shell tachyon amplitude. Only recently have the off-shell four-tachyon amplitude[4] and the four-point contribution to $V(\phi)$ (Ref. 5) been obtained. At present, the higher-order tree contributions involve arduous computa-

Theory of LI violation framework

PHYSICAL REVIEW D **66**, 056005 (2002)

Signals for Lorentz violation in electrodynamics

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(Received 20 May 2002; published 23 September 2002)

An investigation is performed of the Lorentz-violating electrodynamics extracted from the renormalizable sector of the general Lorentz- and CPT-violating standard-model extension. Among the unconventional properties of radiation arising from Lorentz violation is birefringence of the vacuum. Limits on the dispersion of light produced by galactic and extragalactic objects provide bounds of 3×10^{-16} on certain coefficients for Lorentz violation in the photon sector. The comparative spectral polarimetry of light from cosmologically distant sources yields stringent constraints of 2×10^{-32}. All remaining coefficients in the photon sector are measurable in high-sensitivity tests involving cavity-stabilized oscillators. Experimental configurations in Earth- and space-based laboratories are considered that involve optical or microwave cavities and that could be implemented using existing technology.

Coordinate transformations

$$x^2 + y^2 + z^2 - c^2t^2 = 0$$ System 1

$$x'^2 + y'^2 + z'^2 - c^2t'^2 = 0$$ System 2

The assumption is that transformation is linear; space-time is homogeneous and isotropic.

Coordinate transformations

$$z' = \frac{z - vt}{\sqrt{1 - \left(\frac{v}{c}\right)^2}} \qquad t' = \frac{t - \frac{v}{c}\frac{z}{c}}{\sqrt{1 - \left(\frac{v}{c}\right)^2}}$$

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Electromagnetic field transformation

$$\mathbf{E}'_{\parallel} = \mathbf{E}_{\parallel} \qquad \mathbf{E}'_{\perp} = \gamma\left(\mathbf{E}_{\perp} + \frac{\mathbf{v}}{c} \times \mathbf{B}_{\perp}\right)$$

$$\frac{d\mathbf{p}}{dt} = e\left(\mathbf{E} + \frac{\mathbf{v}\times\mathbf{B}}{c}\right)$$

Lorentz factor

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

When the value of the speed 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.

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

Measurement of the Lorentz factor

could be done with high relative accuracy
for an electrically charged particle

$$\frac{d\mathbf{p}}{dt} = e\left(\mathbf{E} + \frac{\mathbf{v}\times\mathbf{B}}{c}\right)$$

Tests of Lorentz Invariance

- Two-way speed via interferometers, cavities
- Doppler effect via atomic beam, ion storage ring

- One-way speed via asymmetric optical ring
- One-way speed via laser-backscattering

- One-way speed via a beam deflection by a magnet

A concept of a new LI test

- A difference of (v-c) values at opposite directions of motion
- Very small initial value of $(v-c)/c \sim 10^{-9}$

The method (BW, EPL, 108 (2014) 31001)

- Momentum measurements at the opposite sides of the arc:
  - Ratio of the momenta provides the measure of $\Delta c/c$.
  - The momenta ratio has a double value of the signal and strongly suppresses the systematics:
    - beam energy variations;
    - magnetic field calibration and common variation;
    - BPM locations drift.
- Search for a sidereal variation of the ratio.

A concept of a new LI test

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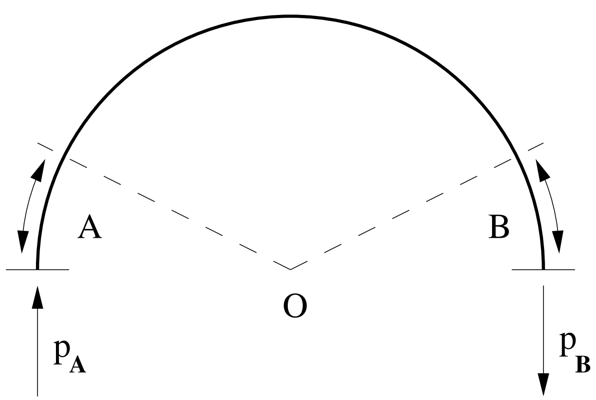
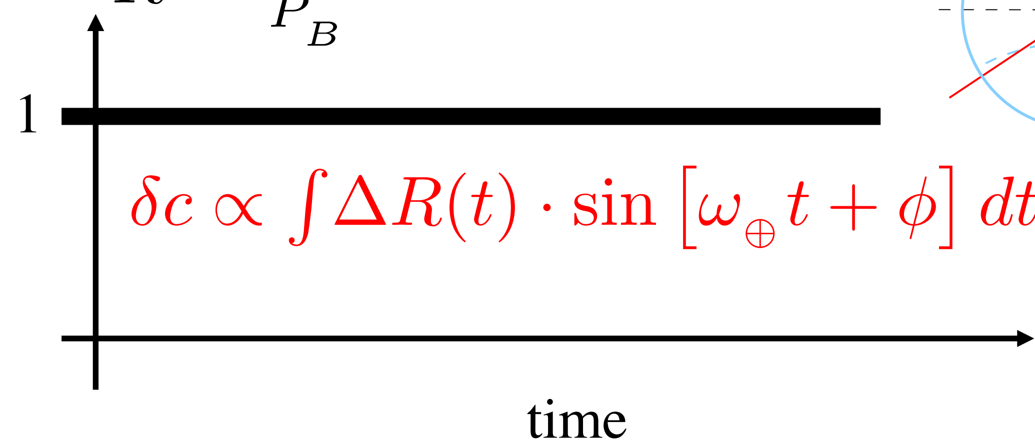
- Very small initial value of $(v-c)/c \sim 10^{-9}$

<u>The method</u> (BW, EPL, 108 (2014) 31001)

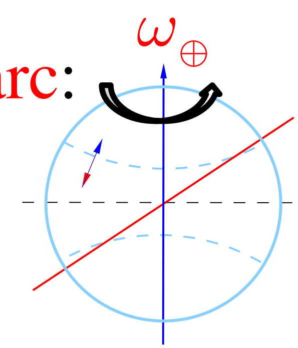
- Momentum measurements at the opposite ends of the arc:



$$R = \frac{P_A}{P_B}$$



$$\delta c \propto \int \Delta R(t) \cdot \sin\left[\omega_{\oplus} t + \phi\right] dt$$



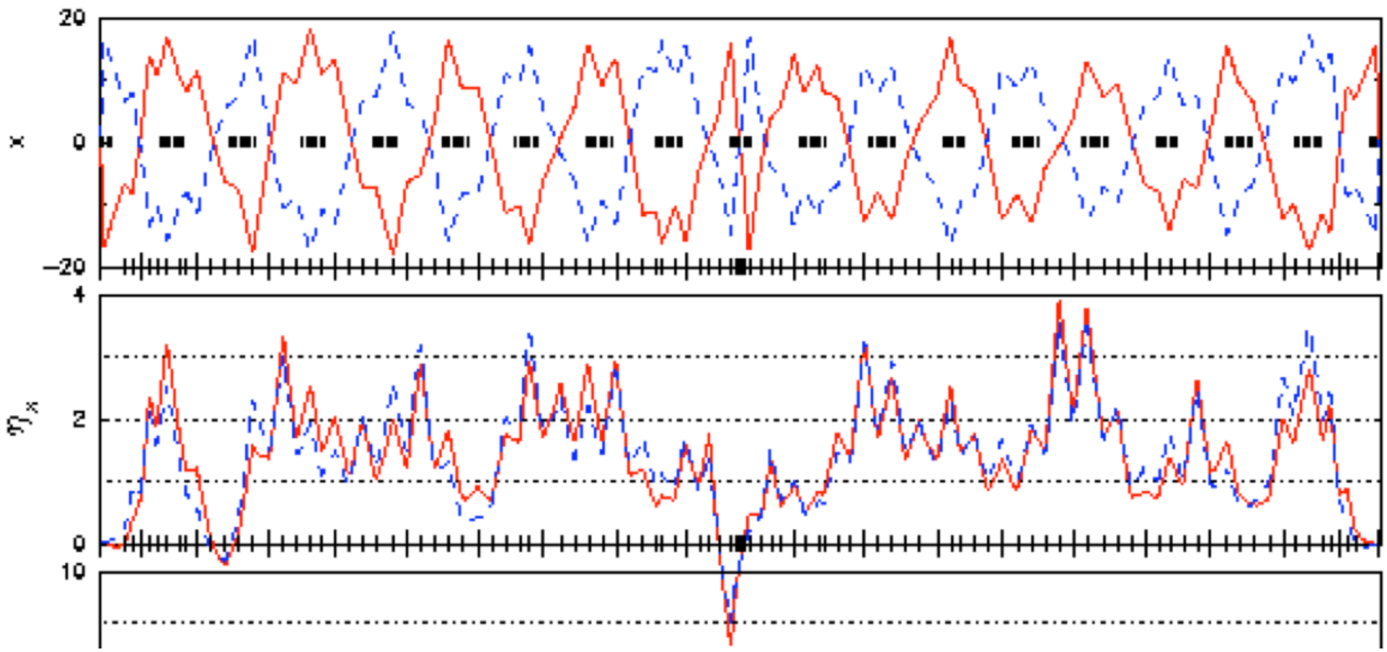
Beam in an accelerator

$$x(s) = x_\beta(s) + \eta(s) \times \frac{\Delta p}{p}$$

Hor. displacement = Dispersion times Momentum deviation

CESR-c Lattice Design and Optimization

D. Rubin, M.Forster



Beam in an accelerator

$$x(s) = x_\beta(s) + \eta(s) \times \frac{\Delta p}{p}$$

Hor. displacement = Dispersion times Momentum deviation

as a first-order estimate using the dispersion along the orbit:

$$\eta_{large} \sim 1.5m \ , \ \sigma_x \sim 50\mu m$$

$$\sigma\left[\frac{p_A - p_B}{p_{aver}}\right] = \sigma\left[\frac{x_A}{\eta_A}\right] \oplus \sigma\left[\frac{x_B}{\eta_B}\right] \sim 0.5 \cdot 10^{-4}$$

A large number of BPMs could be used for higher accuracy.

Beam in an accelerator

$$x(s) = x_{\beta}(s) + \eta(s) \times \frac{\Delta p}{p}$$

$$\frac{\sigma_{\Delta p}}{p} = \sigma\left[\Delta \frac{x}{\eta}\right] \oplus \frac{x}{\eta} \cdot \frac{\sigma_{\eta}^{time}}{\eta}$$

consider the first term statistics over 100 seconds:

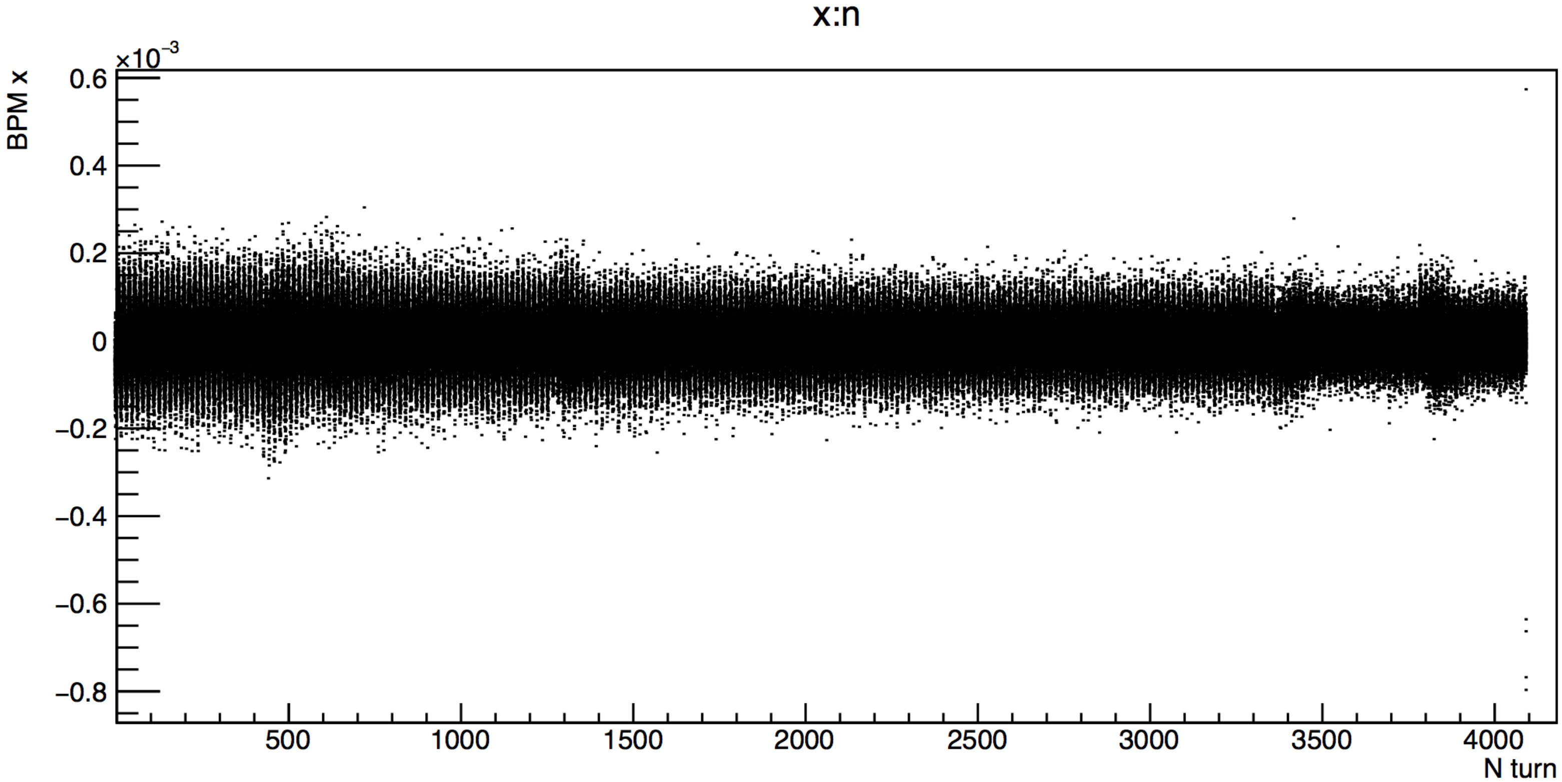
$$\frac{\sigma_{\Delta p}}{p} = 0.5 \cdot 10^{-4} \times \sqrt{\frac{2.5 \cdot 10^{-6}}{100}} \sim 10^{-8}$$

Beam in an accelerator

$$x(s) = x_\beta(s) + \eta(s) \times \frac{\Delta p}{p}$$

Hor. displacement = Dispersion times Momentum deviation

How large statistics could be used?



D. Rubin's data 12/2014

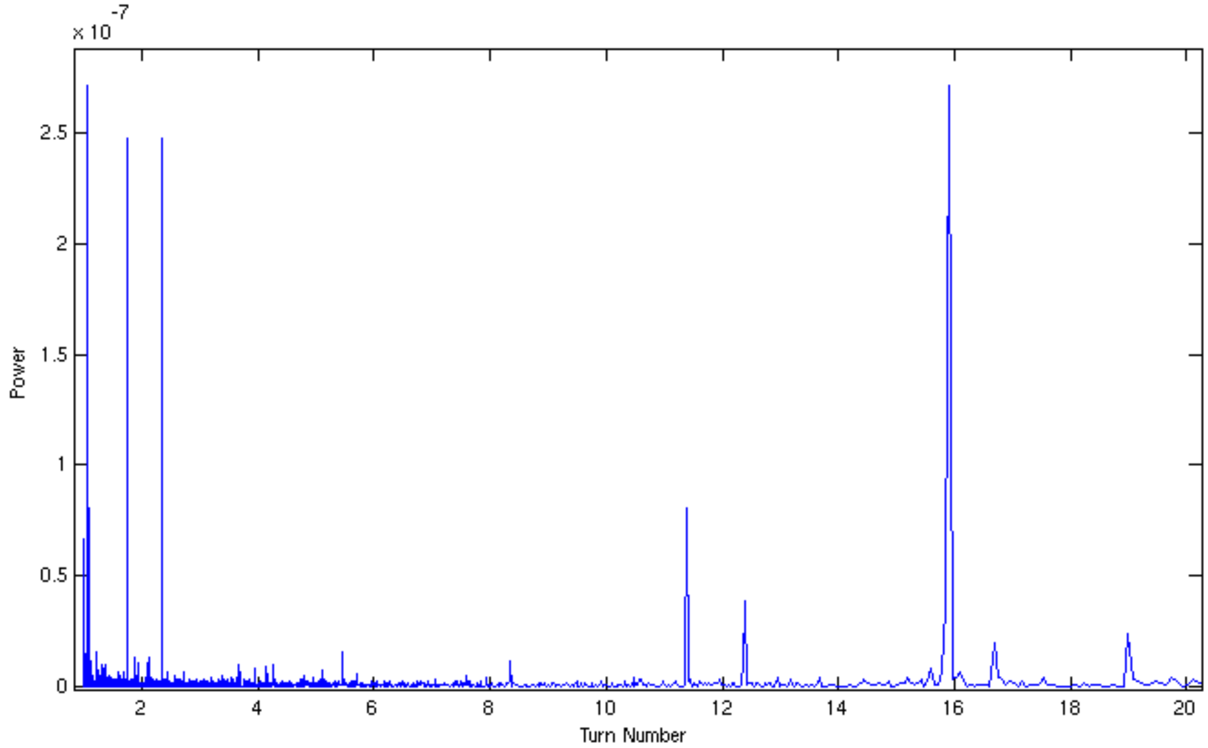
all BPMs

Beam in an accelerator

$$x(s) = x_\beta(s) + \eta(s) \times \frac{\Delta p}{p}$$

Hor. displacement = Dispersion times Momentum deviation

How large statistics could be used?



D. Rubin's
data 12/2014

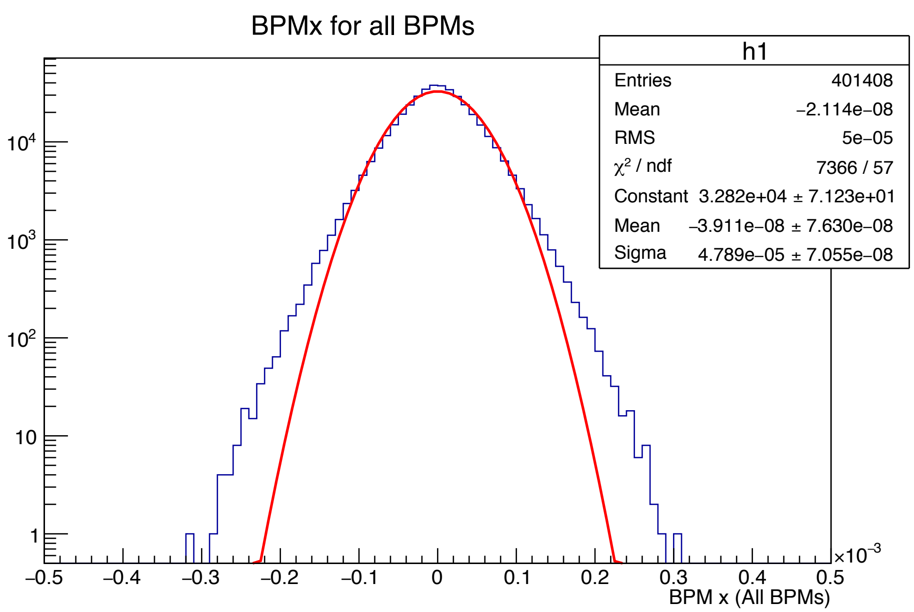
one BPM

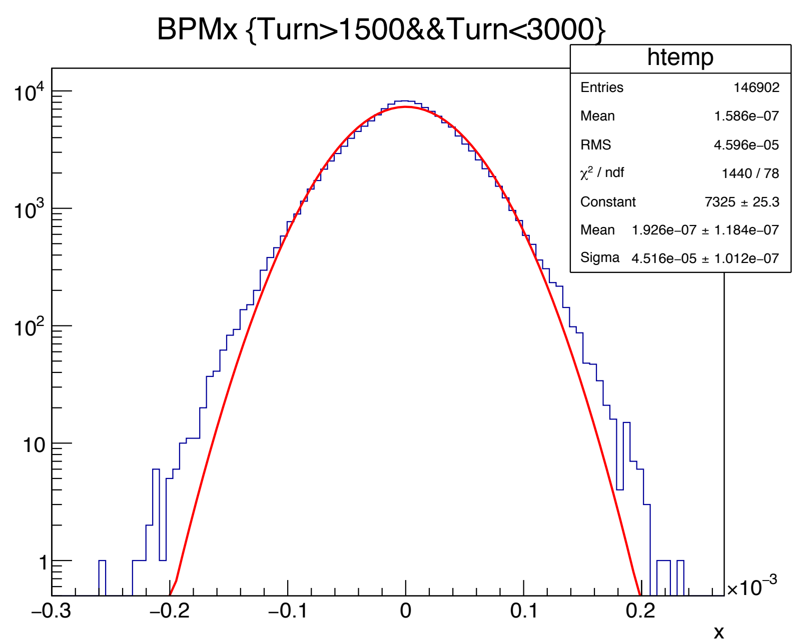
Beam in an accelerator

$$x(s) = x_{\beta}(s) + \eta(s) \times \frac{\Delta p}{p}$$

Hor. displacement = Dispersion times Momentum deviation

How large statistics could be used?





Beam in an accelerator

$$x(s) = x_{\beta}(s) + \eta(s) \times \frac{\Delta p}{p}$$

Hor. displacement = Dispersion times Momentum deviation

consider the second term statistics and systematics

$$\frac{\sigma_{\eta}^{time}}{\eta}$$

Beam in an accelerator

Stability of the measurement: the σ_η^{time}/η and BMPs are the main subjects of investigation to do.

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NEW EXPERIMENT ON THE PRECISE COMPARISON OF THE ANOMALOUS MAGNETIC MOMENTS OF RELATIVISTIC ELECTRONS AND POSITRONS

I.B. VASSERMAN, P.V. VOROBYOV, E.S. GLUSKIN, P.M. IVANOV, G.Ya. KEZERASHVILI, I.A. KOOP, A.P. LYSENKO, A.A. MIKHAILICHENKO, I.N. NESTERENKO, E.A. PEREVEDENTSEV, A.A. POLUNIN, S.I. SEREDNYAKOV, A.N. SKRINSKY and Yu.M. SHATUNOV

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Received 12 November 1986

A comparison of the anomalous magnetic moments of the electron and positron has been performed using the resonance depolarization method for the VEPP-2M storage ring beams. It has been shown that the difference between the anomalous magnetic moments of the electron and positron does not exceed 1.2×10^{-7} with 95% confidence level, in agreement with the *CPT*-theorem and the principle of relativistic invariance.

Beam in an accelerator

Stability of the measurement: the $\sigma_{\eta}^{time}/\eta$ and BMPs are the main subjects of investigation to do.

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torage ring beams. It has been shown that the differenc
does not exceed 1 2×10^{-7} with 95% confidence level, i

The e$^+$ e$^-$ energy difference is also of 1.2 x 10^{-7} over a few days/weeks of the experiment.

Beam in an accelerator

$$x(s) = x_{\beta}(s) + \eta(s) \times \frac{\Delta p}{p}$$

Hor. displacement = Dispersion times Momentum deviation

Back to statistical estimations:

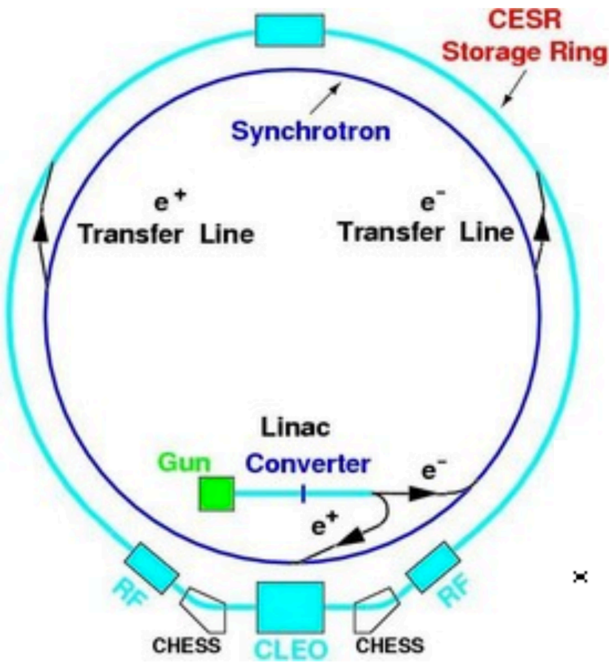
$$\frac{\sigma_{\Delta p}}{p} = 10^{-8}$$ a short time ~100 s

A measurement over 24 hours => $\frac{\sigma_{\Delta\gamma}}{\gamma} = 3 \cdot 10^{-10}$

a few days' experiment: $\delta c/c \sim 10^{-18}$

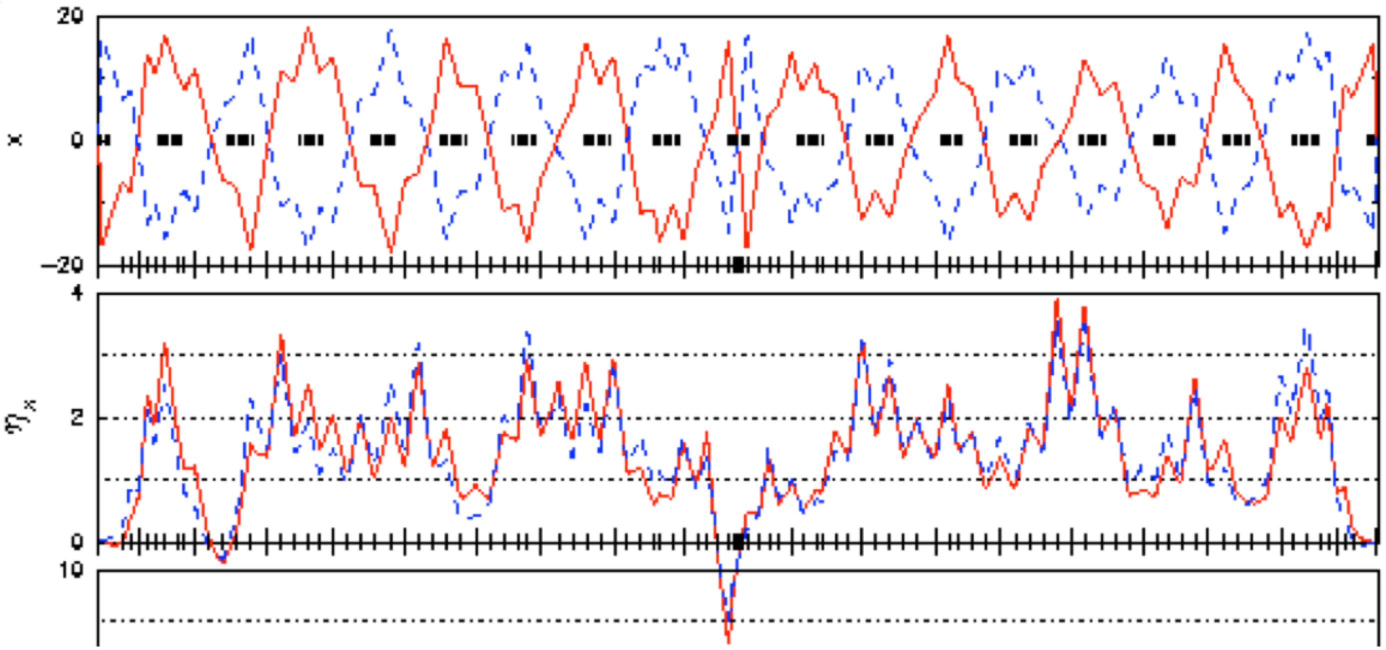
It would be 10,000 times better than the current limit for the one-way $\delta c/c$.

CESR lattice



CESR-c Lattice Design and Optimization

D. Rubin, M.Forster



Beam in an accelerator

$$x(s) = x_\beta(s) + \eta(s) \times \frac{\Delta p}{p}$$

The currently observed accuracy ~ 50 μm in 2.5 μs

a one day: 24 measurements of 4 minutes each
with 2 minutes for e^+ and e^-

An anticipated precision on the level of $\delta c/c \sim 10^{-16}$

It would be a very important proof of the method
(and 100 times better than currently known).

Beam in an accelerator

Synchrotron radiation effects

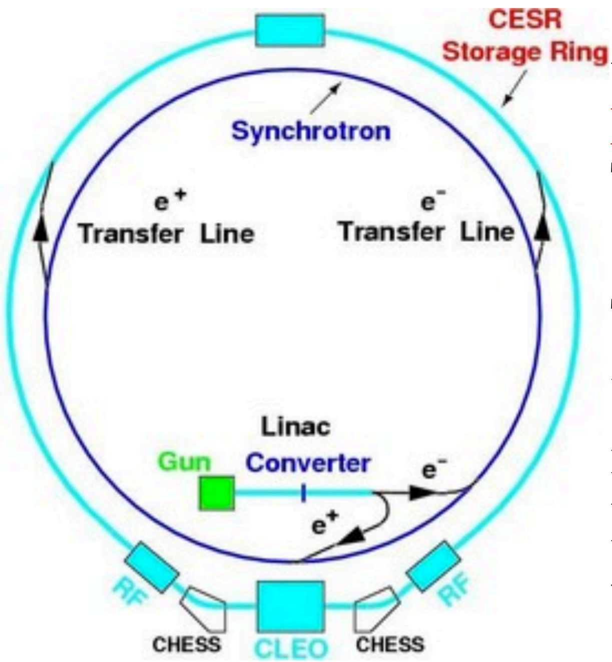
The radiation loss is 1 MeV/turn at 5.3 GeV
or about 1×10^{-4} for 1/2 turn path.

How large is the instability over 120 seconds?

How large is the difference for e^+ and e^- beams?

Correction for the beam energy variation could be made using data from a short arc section and/or the 90^o (orthogonal) diameters.

Accelerator experiment



An important feature of CESR is that the electron and positron beams are in the same magnetic arc.
The RF cavities are localized: A long arc could be used!

The e+, e- beam orbits could be made almost identical, which would allow a cross calibration of the momentum measurement.
By using one beam at a time (no beam-beam effects) the cross calibration could be done every 120 seconds.

The drift of the dispersion (120 seconds) is ~ 10^{-10} (?)

Required beam time (for the production run):
2 x 120s x 24 times per day x100 days ~ 80 hours

The sensitivity would be $\Delta c/c \sim 10^{-18}$

about 25 microns per day

Summary

- A search for possible anisotropy of the maximum attainable speed is proposed using high energy electron (and/or positron) beam deflections in a magnetic arc.

- Existing accelerators should allow to reach a significantly tighter limit (three-four orders) on a one-way variation of the maximum attainable speed than the best currently known of 10^{-14}.

- The CESR unique positron/electron beam combination provides a natural way to improve the effective stability of a magnetic arc. It could open the way to an accuracy of 10^{-18} (a level of a possible onset of the quantum gravity effects).

Experiments are diamonds

The speed of the light is forever