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Search for Intrinsic Anisotropies of Time Dilation

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Abstract

In general, experiments locking for a preferred reference system (ether) search for an anisotropy of physical processes. This anisotropy is studied by making pencils of light travel in round trips, or by making cosmic observations of one-way trips of light in different seasons or at different hours of the day. The first class of experiments is insensitive to effects that are linear in the velocity of the laboratory with respect to the ether; both classes would fail to detect an ether such that the velocity of light is constant in modulus for every frame. This letter reports on a test of the isotropy of Lorentz transformations for time dilation, done by comparing the lifetimes τ of K_S^0 mesons moving parallel and antiparallel to arbitrary directions in a frame of reference fixed to the solar system. The maximum anisotropy $\Delta\tau/\tau = (\tau_+ - \tau_-)/(\tau_+ + \tau_-)$ was found to be about 4%, with probability $P \simeq 5\%$ of coming from a statistical fluctuation. If interpreted as a null result, this gives an upper limit $\Delta\tau/\tau < 0.082$, at 95% Confidence Level. This result sets a limit to non-relativistic theories, and to possible anisotropical interactions of neutral kaons with the matter in the Universe, in a domain that is, to the knowledge of the author, unexplored, and suggests a new technique for investigating anisotropies.

The precise verifications of time dilation published up to now (using particle lifetimes) do not exclude the possibility that the lifetime depends on the direction of flight. The following is a (naive) scenario in which this could be relevant. Suppose for example that an ether (defining a frame of reference $\tilde{\Sigma}$) exists such that the Lorentz-Fitzgerald transformations hold in it. Let v be the speed (unless otherwise specified, units c=1 will be used throughout) of a particle in a system Σ moving with speed V with respect to such an ether. The speed $\tilde{v}$ of the same particle seen by $\tilde{\Sigma}$ will be

$$\tilde{v} = \frac{\sqrt{v^2 + V^2 + 2vV\cos\alpha - v^2V^2\sin^2\alpha}}{1 + vV\cos\alpha}, \tag{1}$$

where α is the angle between the particle momentum in Σ and the absolute velocity of the frame with respect to the ether. If the decay process is absolute, and driven by $\tilde{\Sigma}$, the lifetime $\tilde{\tau}$ of the particle will be dilated by a factor

$$\gamma' = \gamma\Gamma(1 + vV\cos\alpha) \tag{2}$$

where $\gamma = \sqrt{1 - v^2}$, $\Gamma = \sqrt{1 - V^2}$. Thus, averaging along α

$$\gamma' = \gamma\Gamma\,. \tag{3}$$

In any lifetime measurement averaging particles with random directions, the observers in the frame Σ will verify the Lorentz transformation, because they will think that the lifetime of the particle is $\tau = \Gamma\tilde{\tau}$. In the following, I will call the ether defined in this paragraph *Lorentzian ether.*

From Eq. (3), the average difference (asymmetry) between the lifetimes of particles parallel and antiparallel to the direction of motion is

$$\frac{\Delta\tau}{\tau} = \frac{1}{2}\int_0^1 2vV\cos\alpha\,\mathrm{d}\cos\alpha = \frac{vV}{2}\,. \tag{4}$$

The investigation of anisotropy of the Universe reported in this letter is based on the search for differences in lifetimes of K_S^0 particles according to their direction. This has the unique feature of being sensitive to a Lorentzian ether in which, for example, the speed of the light is the same for every reference frame. In addition, such a search can put limits on nonrelativistic models, as well as, more specifically, to anisotropical interactions of K_S^0 with the matter in the Universe.

The technique uses the fact that collider detectors with 4π acceptance can be used as a probe for detecting asymmetries in the Universe. The rotation of the Earth provides in the different seasons and hours of the day different orientations of the symmetry axes with respect to arbitrary directions, that allow detector effects to be averaged out.

The LEP electron-positron collider is located at CERN near Geneva, at a latitude of $46°10'$. In collision point 8, the DELPHI detector[1] registers the decays of the Z^0 particle. DELPHI is a cylinder whose axis points about $33.75°$ North of East (Fig.1).

Due to the rotation of the Earth, about every 86,400 s the DELPHI detector makes a complete rotation as seen from the Sun. The yearly revolution around the Sun causes the rotational period to be about 86,164.09 s with respect to the "fixed stars" (sidereal day).

The search for anisotropy of time dilation used the sample of $K_S^0 \to \pi^+\pi^-$ selected in Ref. [2]. This corresponds to 10,624 decays, with a combinatorial background less than 10%.

First the directions of the K_S^0 were expressed in a frame of reference in which the η axis is directed along the polar axis, the ζ axis goes from East to West as in Geneva at 23:00 GMT of 31 December 1989, and ξ is selected in such a way to have an orthonormal right-handed system $\xi\eta\zeta$. This transformation made the approximation that a rotation of the Earth with respect to the fixed stars happens always in a sidereal day (i.e., neglected the ellipticity of the Earth's orbit). The frame of reference (fixed reference frame in the following) is shown in Fig.2.

Then the asymmetry in the lifetime of the K_S^0 was explored in the positive and negative directions with respect to an arbitrary axis in the fixed frame. The lifetime was determined by computing correction factors from a simulation of detector effects for each interval of proper time corresponding to $\Delta(ct) = 1$ cm, and then fitting to an exponential decay function. The same procedure was used in [2].

Let us define

$$\frac{\Delta\tau}{\tau} = \frac{\tau_+ - \tau_-}{\tau_+ + \tau_-}, \tag{5}$$

where τ_+ (τ_-) is the lifetime of kaons travelling along the positive (negative) direction of the axis. The absolute value of the asymmetry $\frac{\Delta\tau}{\tau}$ as a function of the components c_ξ along ξ and c_η along η of the unit vector corresponding to the axis explored, divided by the statistical error from the fit, displays its maximum at $c_\xi \simeq -0.27$, $c_\eta \simeq 0.73$.

The maximum asymmetry is

$$\frac{\Delta\tau}{\tau} = 0.041 \pm 0.014\,(stat, fit)\,. \tag{6}$$

The presence of systematic errors that should cancel the significance of the result in Eq. (6) is reduced by the fact that, in a frame of reference moving with the detector, the number of K_S^0 with a line of flight parallel and antiparallel with respect to each coordinate axis is compatible within 30% in the two samples asymmetric in the fixed reference frame. Thus, systematic effects due to asymmetries of the detector should in principle cancel in definition (1). In addition, such effects are not seen in a frame of reference fixed with the detector, nor in data simulated via Monte Carlo.

However, the statistical significance of (6) is not three standard deviations. Asymmetries are searched in arbitrary directions, and then the result with the most significant asymmetry found is quoted. In order to estimate the significance of the result, the following procedure was used:

1. First the K_S^0 in the sample were reshuffled, mixing the lifetime of one with the direction of another one randomly chosen.
2. Then the same programs used for the data sample were applied to this artificial sample, and found the significance of the maximum asymmetry observed.

This procedure was repeated 1,000 times.

The most significant asymmetry found in such samples (that should be free of asymmetry) is:

a. in 31.7% of the cases larger than 2.06 times the statistical error from the fit,
b. in 4.5% of the cases larger than 3.02 times the statistical error from the fit,
c. in 5% of the cases larger than the actual statistical significance found in the data.

Thus taking the probability that the result comes from a fluctuation to be about 5%, and rescaling the $\pm 1\sigma$ confidence interval according to a., the result (6) becomes

$$\frac{\Delta\tau}{\tau} = 0.041 \pm 0.029\,, \tag{7}$$

or, if interpreted as a null result,

$$\frac{\Delta\tau}{\tau} < 0.082\,(95\%\,\mathrm{CL})\,. \tag{8}$$

This result puts limits on ether theories in a new domain. In a naive model of ether in which speeds add according to Lorentz-Fitzgerald transformations and the decay process is absolute and driven by the ether reference frame, a bound is obtained on the absolute velocity V of the solar system with respect to the ether. By folding this upper limit with Eq. (4), and assuming $v \simeq 1$, one has

$$V < 49 \times 10^6\,\mathrm{ms}^{-1}\,(95\%\,\mathrm{CL})\,. \tag{9}$$

Interpreting the peak asymmetry as an effect of an absolute speed V of the solar system would give, by folding Eq. (8) with Eq. (4)

$$V = (25 \pm 17) \times 10^6\,\mathrm{ms}^{-1}\,. \tag{10}$$

It would be interesting to reanalyze the data from Ref. [3] using Eq. (2), in order to see if the non-Lorentzian energy dependence of the K^0_S claimed in that article could be interpreted as a consequence of (2).

The study will be extended to a larger statistics. With 100,000 reconstructed K^0_S (expected from DELPHI 1991+1992 data), a sensitivity to absolute velocities as small as 0.015 c can be reached. Results more precise by a factor of 100 can be reached in one year at ϕ factories, that can thus be sensitive to the effect of the velocity of the solar system with respect to the centre of our galaxy.

Acknowledgments

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References

[1] Aarnio P. et al. (DELPHI Collaboration), *Nucl. Instr. and Meth.* **A303**, 233-276 (1991)
[2] Aarnio P. et al. (DELPHI Collaboration), *Phys. Lett.* **B275**, 231-242 (1992)
[3] Aronson S.H. et al., *Phys. Rev.* **D28**, 476-494 (1983)

Figure captions

1. Layout of LEP (a) and DELPHI (b).
2. The "absolute" reference frame.

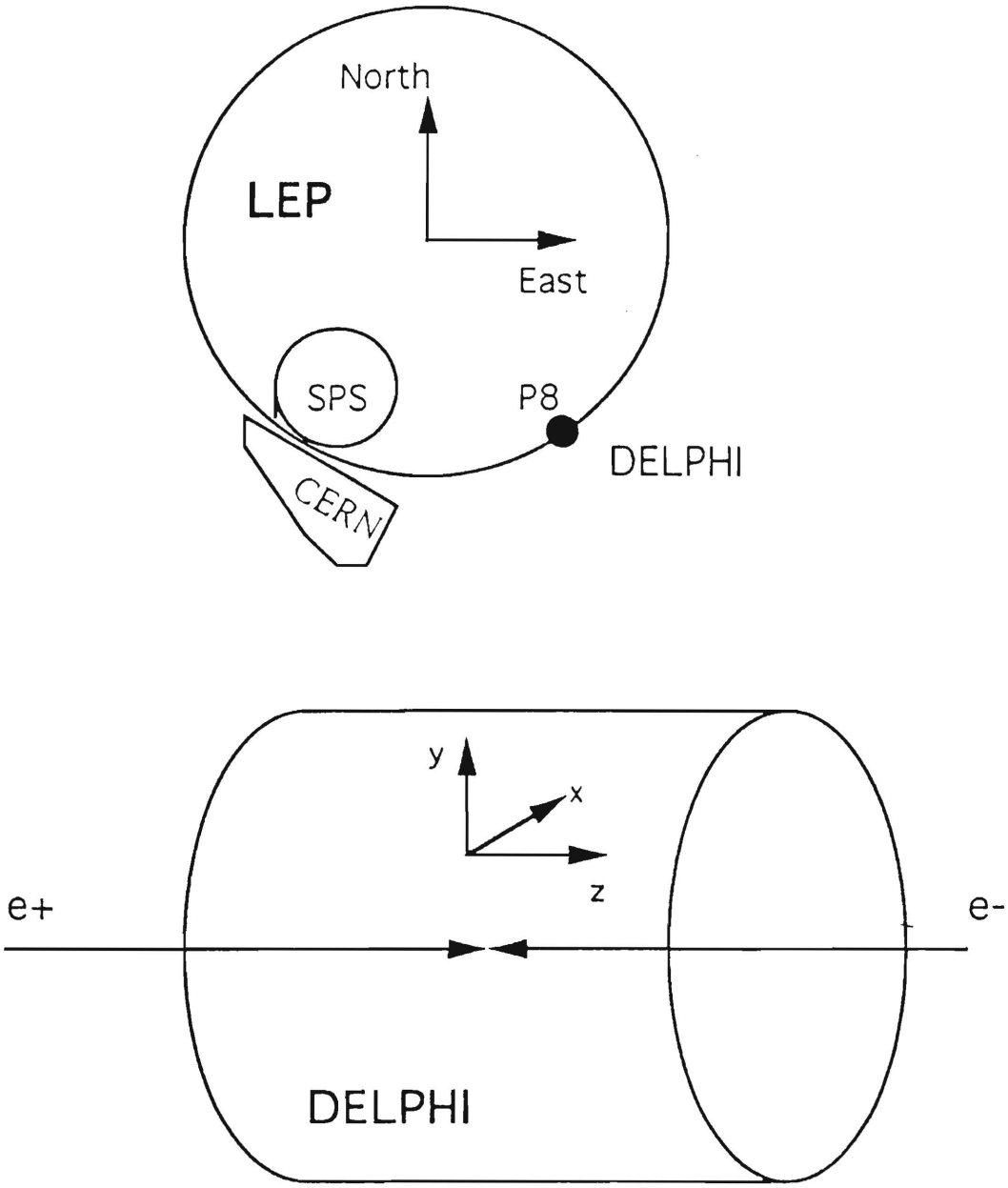

Fig.1

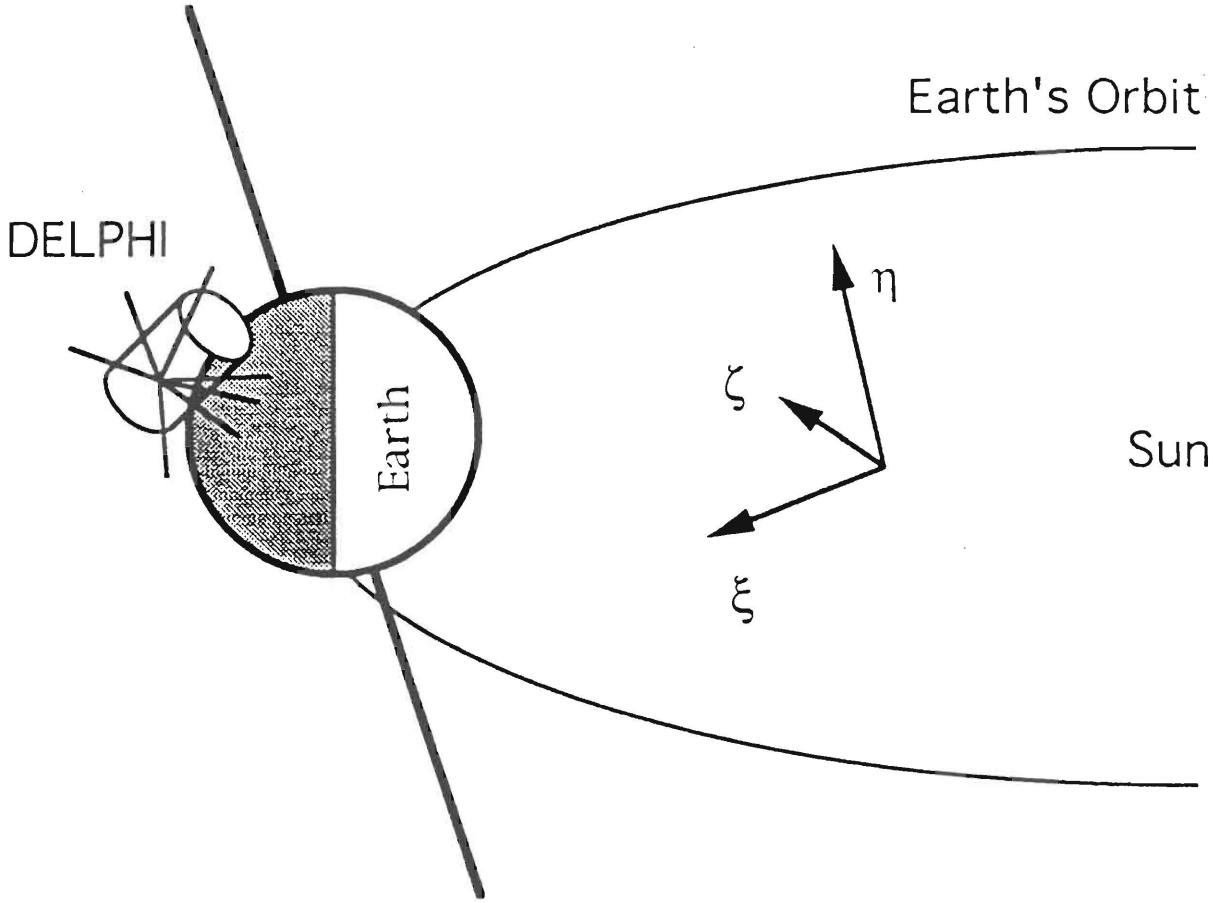

Fig. 2