A new test of Time Dilation at ESR using fast $^{7}Li^{+}$-ions

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One of the fundamental principles in modern physics is Local Lorentz Invariance (LLI), which describes spacetime symmetry in the theories of the electromagnetic, the strong and the weak force as well as the local part of general relativity. Time dilation is one of the well known consequences of LLI and Special Relativity (SR), respectively, and can be probed by experiment. Such a test can be performed by simultaneous excitation of an electric dipole transition of fast moving ions. The presented experiment uses $^{7}Li^{+}$ ions, stored at the experimental storage ring (ESR) with an velocity of 33,8 % of the speed of light. The schematic setup is shown in figure 1.

In the used experiment geometry the wavelengths of the excitation lasers ($\lambda_{a,p}$) and the wavelength of the dipole transition of metastable $^{7}Li^{+}$ ions at rest (λ_0 = 548,5 nm) have to obey

$$\frac{\lambda_a \cdot \lambda_p}{\lambda_0^2} = 1 \quad (1)$$

if SR is valid. Here, λ_a (λ_p) denotes the wavelength of the laserbeam which is aligned antiparallel (parallel) to the flight direction of the ions. In test theories [1, 2] hypothetical deviations from SR can be addressed by a dimensionless parameter $\varepsilon(\beta^2)$ added to eq. (1)

$$\frac{\lambda_a \cdot \lambda_p}{\lambda_0^2} = 1 + \varepsilon(\beta^2) \quad . (2)$$

By using the Einstein clock synchronisation the experiment is not sensitve to the one-way speed of light and therefore the parameter $\varepsilon(\beta^2)$ is only dependent on orders of β^2.

Due to the relativistic time dilation, the wavelengths of the exciting lasers have to obey $\lambda_{a,p} = \lambda_0 \cdot \gamma \cdot (1 \pm \beta)$, where $\gamma = (1 - \beta^2)^{-1/2}$ is the well-known Lorentz factor and $\beta = v/c$ is the velocity of the ions in terms of the speed of light. With this setup the frequencies of the lasers can be fixed down to 1 MHz which corresponds to a relative accuracy of $\Delta\nu/\nu = 10^{-9}$.

During the beam time in February 2009 the transition frequencies ν_a and ν_p of the moving ions have been determined to an overall accuracy of $\Delta\nu/\nu = 10^{-8}$ which is a factor 10 more accurate than the previous experiment at GSI [3]. This leads to an upper bound for the parameter $\varepsilon(\beta^2)$ of

$$\varepsilon(\beta^2) < 1{,}6 \cdot 10^{-8} \quad . (3)$$

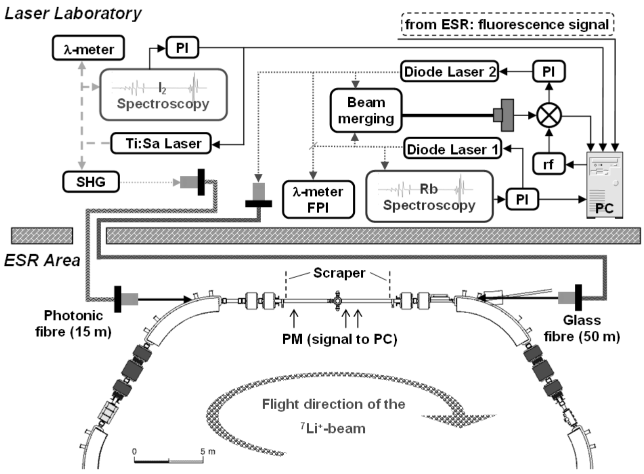

Figure 1: Schematic setup of the laser spectroscopy experiment for a test of time dilation at ESR. The laserlight for the antiparallel excitation (λ_a = 780 nm) of the lithium ions is provided by a diode laser, while the light for the parallel excitation (λ_p = 386 nm) is generated by a frequency-doubled Ti:Sa laser. The wavelengths of both lasers are stabilised to well known transitions in atomic rubidium and molecular iodine using frequency modulation spectroscopy.

In the photon sector of the Standard Model Extension [4] $\varepsilon(\beta^2)$ can be expressed by an expansion in terms of β^2 with a coefficent κ_{tr}

$$\varepsilon(\beta^2) = 2 \cdot \kappa_{tr} \cdot \beta^2 + O(\beta^4) \quad . (4)$$

This parameter is interpreted as vacuum birefringence and the presented experiment gives an upper limit for deviations from zero of

$$\kappa_{tr} < 7{,}05 \cdot 10^{-8} \quad . (5)$$

This is comparable with the most stringent previous test [5]. Within the uncertainties of the experiment, no deviations from SR are found. In upcoming beam times, we expect to reduce the upper bound of κ_{tr} by a factor of 10.

References

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