Laser spectroscopy on fast ^{7}Li$^+$ ions
for a test of Lorentz invariance

One of the fundamental principles in modern physics is Local Lorentz Invariance (LLI), on which the theory of Special Relativity (SR) is based. Special Relativity can be probed by a careful measurement of time dilation. For this, an accelerated ion-beam of ^{7}Li$^+$ ions at a velocity (v) of 33,8 % of the speed of light (c) is illuminated by two laser beams to excite the moving ions. The lithium ions are produced by an PIG ion source, accelerated in the SIS18-synchrotron and stored in the experimental storage ring at the GSI Helmholtzzentrum für Schwerionenforschung. The laser beams are aligned parallel and antiparallel to the flight direction of the lithium ions and the frequencies of the lasers are adjusted to drive the 2s ^{3}S$_1 \rightarrow$ 2p ^{3}P$_2$ transition ($\lambda_0 = 548$ nm). Due to the Doppler-shift the laser wavelengths (λ_a, λ_p) have to obey $\lambda_\mathrm{a,p} = \lambda_0 \cdot \gamma \cdot (1 \pm \beta)$ where $\gamma = (1-\beta)^{-1/2}$ and $\beta = \mathrm{v/c}$. The excitation wavelengths are shifted to $\lambda_\mathrm{p} = 386$ nm for the parallel and to $\lambda_\mathrm{a} = 780$ nm for the anti parallel aligned laser. By performing a simultaneous measurement with both lasers, the Doppler equation for the three wavelengths changes to $\lambda_\mathrm{a} \cdot \lambda_\mathrm{p}/\lambda_0 = 1 - \varepsilon(\beta^2)$. Here the additional parameter $\varepsilon(\beta^2)$ denotes hypothetical deviations from SR and vanishes if SR is valid. It can be parameterized in different frameworks of kinematic [1] and dynamic [2] test thories. In both cases $\varepsilon(\beta^2)$ is expanded in terms of β, e. g. in the Robertson-Mansouri-Sexl test theory the representation of $\varepsilon(\beta^2)$ is given as $\varepsilon(\beta^2) = 2 \cdot \alpha \cdot \beta^2 + \mathcal{O}(\beta^4)$.

The setup allows a frequency accuracy of $\Delta\nu/\nu = 10^{-9}$. This precision is provided by a laser stabilization scheme using saturation spectroscopy on rubidium and iodine. Considering all other experimental uncertainties, this leads to an upper bound for hypothetical deviations from SR of the order of 10^{-8}. In our recent measurements the results of the so far leading experiment [3] has been improved by roughly a factor of 4.

[1] R. Mansouri, and R. U. Sexl, General Relativity an Gravitation **8**, 497 - 513 (1977)
[2] D. Colladay, and V. A. Kostelecký, Physical Review D **58**, 116002 (1998)
[3] S. Reinhardt et al., Nature Physics **3**, 861 - 864 (2007)