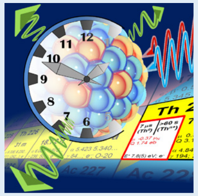
Overview

In the **MPG-RIKEN-PTB Center for Time, Constants and Fundamental Symmetries**, experimental physicists with a passion for precision jointly address forefront topics in low-energy fundamental physics, measurements of time and the determination of fundamental constants.

The research program includes the development of precision instruments with unprecedented resolution to investigate the basic laws of nature with highest resolving power to better understand our Universe.

Exchange of young scientists and combination of the different experimental methods and approaches of the Center partners is expected to produce exciting synergies.



Research

The scientific topics include:

- **Sympathetic cooling of antiprotons**
  MPIK, MPQ, RIKEN, PTB
- **Measurement of the magnetic moment of ^{3}He**
  MPIK, RIKEN
- **Transportable Antiproton Containers**
  MPIK, RIKEN, PTB
- **Advanced ion traps and manipulation techniques**
  MPIK, MPQ, RIKEN, PTB
- **High-resolution spectroscopy of hydrogen**
  MPQ, PTB
- **Hydrogen lattice clock**
  MPQ, RIKEN, PTB
- **Th-229 nuclear clock**
  MPIK, MPQ, RIKEN, PTB
- **Optical and XUV clocks with highly charged ions**
  MPIK, MPQ, RIKEN, PTB
- **Transportable optical clocks**
  MPQ, RIKEN, PTB

Center Partners

MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

MPQ

Prof. Dr. Klaus Blaum
Prof. Dr. Thomas Udem
Prof. Dr. Thomas Pfeifer

RIKEN

Dr. Stefan Ulmer
Prof. Dr. Hidetoshi Katori
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PTB

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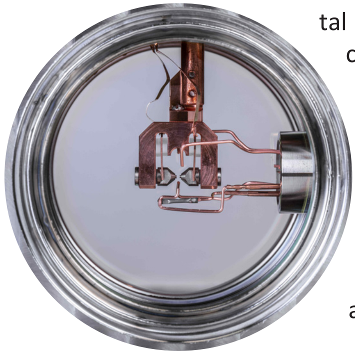
MPG-RIKEN-PTB Center

Time Constants Fundamental Symmetries

TC FS

Time

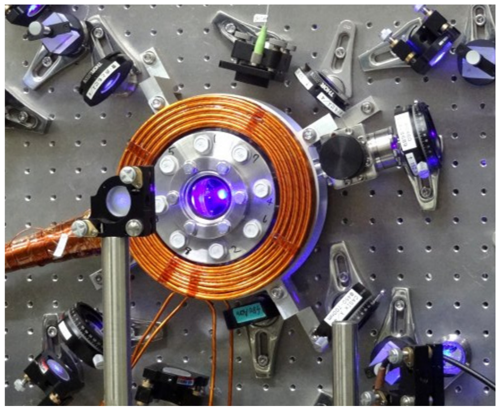
Atomic clocks are the most precise devices constructed by mankind, and measurements of time and frequencies have been crucial in experiments on which the foundations of quantum theory and the theory of relativity are based. Examples are the determination of ephemerides of astronomical objects and of atomic transition frequencies.



The development of experimental methods of trapping and laser cooling of atoms and ions, of the optical frequency comb generator, and, more recently, of quantum state manipulation with individual particles have led to a new generation of optical clocks which promise significant improvements in accuracy.

Comparisons of different clocks provide a sensitivity to possible effects of 'new physics' that are expected in the domain of quantum gravity, like violations of Lorentz symmetry and temporal drifts of the fundamental coupling constants. Clocks are also proposed as a means to detect dark matter composed of ultralight particles.

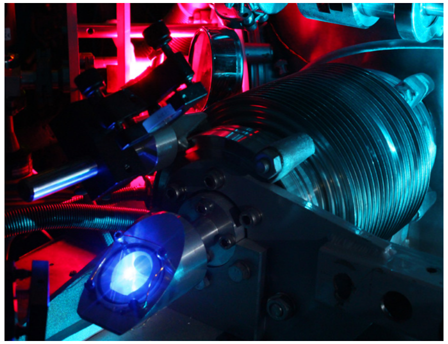
Novel kinds of optical clocks may be based on a low-energy nuclear transition in ^{229}Th, on highly charged ions with tightly bound electrons, and also on the most simple atom, hydrogen, with its calculable level structure. Within the center such new exciting horizons in clock experiments and spectroscopy will be developed and studied.



Constants

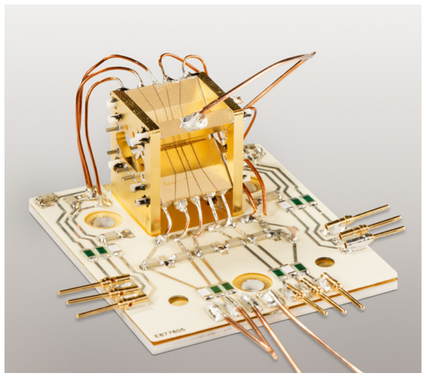
The properties of the basic building blocks of matter form a network of fundamental constants, which is indispensable to perform stringent tests of the predictions of modern physical theories. Using high-precision measurements in ion traps and high-resolution laser spectroscopy on simple atomic systems, members of the center performed several world-leading measurements of complementary physical constants.

For example, the most precise determination of the atomic mass of the proton, reaching a precision of 30 parts per trillion, serves as crucial input datum for analyzing atomic spectra using QED, and for determination of other fundamental constants, such as the Rydberg constant.



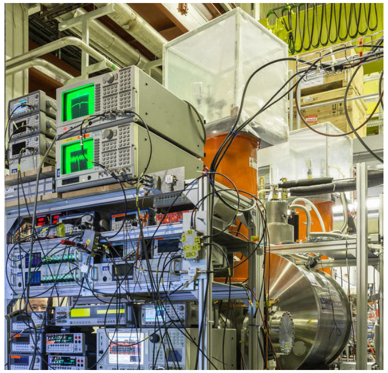
At the same time, laser spectroscopy of atomic hydrogen allows to determine the Rydberg constant and the radius of the proton. By checking the consistency of these values, QED can be verified with very high precision. Within the center, possibilities to cool and trap hydrogen will be explored. This could allow setting up a hydrogen lattice clock – the only one that possesses a computable clock frequency.

With new trapping techniques, ultra-precise optical clocks are under development. This will enable tests of a possible variation of the fine-structure constant α in time and of violations of Lorentz-invariance. Furthermore, the development of ultraviolet frequency combs will enable future fundamental physics tests with highly charged ions enhancing the sensitivity of frequency metrology to new physics.



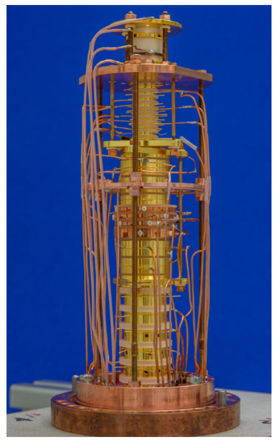
Fundamental Symmetries

Precise and accurate studies of simple physical systems, such as particles in traps or light atoms, probe our current understanding of nature and open up the intriguing perspective to explore new physics beyond the Standard Model. The groups involved in the center performed several world record measurements in this sector.



Using Penning traps, the BASE collaboration compared the fundamental properties of the proton and the antiproton with ultra-high precision, down to 11 significant digits. Such experiments test the fundamental charge-parity-time invariance to better understand why our universe is made out of matter. To further improve the precision, novel experimental techniques will be developed, such as transportable antiproton traps and sympathetic cooling of antiprotons by laser-cooled beryllium ions, which will outperform contemporary methods and enable measurements at even shorter time scales and with improved sensitivity.

Within the center a new experiment will be developed to directly measure the nuclear magnetic moment of $^{3}He^{2+}$ and the ground-state hyperfine splitting in $^{3}He^{+}$. This will establish ^{3}He as a new magnetometer standard, which has potential to contribute, e. g., to measurements of the *g*-2 value of the muon.



Other crucial experiments involved in the center are the ultra-high-precision mass spectrometers PENTATRAP and ALPHATRAP. The instruments perform ultra-stringent tests of QED in strong fields and provide input parameters for the study of the basic nature of the neutrino.