Fundamental Symmetries Laboratory

Ulmer, Stefan (PhD)

Key Sentence：
1. Measure the magnetic moment of the proton and the antiproton with sub-parts per billion-precision and improve current accuracy by a factor at least 10.
2. Measure the proton to antiproton charge-to mass ratio with ppt precision (improvement by a factor of 10).
3. Measure the ground state hyperfine splitting of Antihydrogen with high precision.

Key Word：
Antiproton, Proton, Antihydrogen, Fundamental Symmetries, Tests of CPT Invariance, Antimatter Research, High Precision Experiments, Antihydrogen GSHFS

Purpose of Research：
All relativistic quantum field theories involved in the standard model of particle physics rely on a perfect symmetry between matter and antimatter conjugates, a property known as charge/parity/time (CPT) invariance. Although CPT is the most fundamental symmetry in the standard model of particle physics, experimental tests are scarce. The research of the Ulmer Fundamental Symmetries Laboratory, leading the BASE collaboration at CERN in Switzerland, is dedicated to investigations of the properties of antimatter/matter equivalents with ultra-high precision, which provides direct CPT-tests. We performed the most precise measurement of the proton magnetic moment, with a fractional precision of 0.3 parts per billion [1], as well as the most precise measurement of the magnetic moment of the antiproton, with a factional precision of 0.8 parts in a million [2]. This measurement has later been improved by a factor of 350 (achieved in 2017) [3], by inventing a new two-particle spectroscopy method, and outperforms the previous best baryon-magnetic-moment based CPT test by more than a factor of 3.000, and that of measurements based on exotic atom spectroscopy by a factor of 2.000.000. In addition to magnetic moment measurements, we compare proton-to-antiproton charge-to-mass ratios. We have reported on such a measurement by determining the cyclotron frequencies of negatively charged hydrogen ions and antiprotons. Thereby we achieved a fractional precision of 69 parts in a trillion, which constitutes to date the most precise test of CPT invariance in the baryon sector [4]. A unique reservoir trap method, also invented by BASE, allows furthermore the direct measurements to the antiproton lifetime. By using this device, we have demonstrated antiproton-storage for in total 405 days, which allows us to set a lifetime limit of >10.2 a [5].
The Ulmer fundamental symmetries laboratory is also involved in a collaborative effort with researchers from the Max Planck Institute for Nuclear Physics, Heidelberg, which determined the mass of the proton in natural units with a precision of 20 parts in a trillion [6]. Moreover, we contribute to ASACUSA antihydrogen research, targeting the measurement of the ground-state-hyperfine-splitting of antihydrogen in a beam [7].

[1] G. Schneider et al. (BASE collaboration), Science **358**, 1081 (2017).
[2] H. Nagahama et al. (BASE collaboration), Nature Comms. **8**, 14084 (2017).
[3] C. Smorra et al. (BASE collaboration), Nature **550**, 371 (2017).
[4] S. Ulmer et al. (BASE collaboration), Nature **524**, 196 (2015).
[5] S. Sellner et al. (BASE collaboration), New J. Phys. **19**, 083023 (2017).
[6] F. Heisse et al., Phys. Rev. Lett. **119**, 033001 (2017).
[7] N. Kuroda et al. (ASACUSA collaboration), Nature Comms. **5**, 3089 (2014).

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