

# Ulmer Initiative Research Unit

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## Key Sentence :

1. Measure the magnetic moment of the proton and the antiproton with ppb-precision and improve current accuracy by a factor of 1000.
2. Measure the proton to antiproton charge-to mass ratio with ppt precision (improvement by a factor of 100).
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 predict a perfect symmetry between matter and antimatter. This property is known as CPT invariance. Although CPT symmetry is the most fundamental symmetry in the standard model, experimental tests are scarce. The research of the Ulmer Initiative Research Unit is dedicated to investigations of the properties of antimatter/matter equivalents with ultra-high precision, which provides direct tests of CPT invariance. We performed the most precise measurement of the proton magnetic moment, with a fractional precision of 3.3 ppb, this result was published 2014 in Nature. The application of this technique to the antiproton will improve the precision of the current CPT test by more than a factor of 1000. Moreover, we are aiming at an improvement of precision in the proton-to-antiproton charge to mass ratio. In a measurement which compared the cyclotron frequencies of negatively charged hydrogen ions and antiprotons, we achieved a fractional precision of 69 ppt, which is to date the most precise test of CPT invariance in the baryon sector. We developed techniques to further improve this measurement by another factor of 10. In addition, we participate in efforts to measure the ground state hyperfine splitting of antihydrogen, which will provide another very stringent test of CPT invariance.

1. The effort to perform high precision measurements of the properties of protons and antiprotons is recognized at CERN, Geneva, under the acronym BASE (Baryon Antibaryon Symmetry Experiment). Our main goal is to compare the proton and the antiproton magnetic moments with a precision of at least one part in a billion (ppb). To this end we developed techniques to observe single proton spin flips, applied the double Penning trap technique with a single proton and performed the most precise measurement of the proton magnetic moment to date. The achieved precision is at the level of 3 ppb and an application of our techniques to the antiproton will improve the precision of the currently accepted value by more than a factor of 1000. In addition we are aiming at an improved precision in the proton-to-antiproton charge to mass ratio, to provide another sensitive test of CPT invariance. To this end we developed the advanced Penning trap experiment BASE. In our first antiproton physics run in 2014 we commissioned this experiment, established techniques to trap antiprotons, to prepare a single antiproton and performed antiproton cyclotron-frequency measurements with a few 10 ppt in precision. This means that the newly developed apparatus is stable enough to achieve the planned measurements at the aimed precision, at least.. Based on this success we managed to perform the most precise test of CPT invariance with baryons by comparing the proton to antiproton charge-to-mass ratio with a fractional precision of 69 ppt.

2. The Ulmer IRU is a collaboration member of the ASACUSA CUSP experiment. The research subject is the precision measurement of the ground state hyperfine splitting of antihydrogen atoms. Combining these data with the results of 1. provides constraints of the substructure of the antiproton. We participate in these efforts by contributing to particle detection, low-noise techniques, radio frequency techniques and Penning traps. Our collaboration reported in 2013 on the first production of a beam of antihydrogen atoms, which is a major step towards performing the aimed spectroscopy.

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