BASE: Ultra-High Precision Measurements of Proton and Antiproton Fundamental Properties

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The BASE collaboration situated at CERN's Antiproton Decelerator facility uses Penning traps to test the Charge-Parity-Time (CPT) symmetry by measuring the fundamental properties of protons and antiprotons to ultra-high precision [1]. One of the properties measured is the dimensionless g-factor which expresses the magnetic moment in units of the nuclear magneton μ_N=q_(p,p¯) ℏ/2m_(p,p¯). The antiproton g-factor is determined by taking the ratio of the Larmor frequency, ω_L, and the free-cyclotron frequency, ω_C, which the BASE collaboration recently measured to 1.5 ppb. This result is consistent with the 0.3 ppb measurement of the proton g-factor, also measured by the BASE collaboration [2]. This measurement improved upon the precision of previous best measurements by a factor of >3000 and was achieved with a completely new measurement scheme utilising two measurement antiprotons and three traps [3].

Another fundamental property which can be measured is the proton-to-antiproton charge-to-mass ratio, $(q/m_{\mathrm{p}})/(q/m_{\bar{\mathrm{p}}})$. Here the free-cyclotron frequency, $\omega_c = qB_0/m_{\bar{\mathrm{p}},\mathrm{H}^-}$, of both $\bar{\mathrm{p}}$ and H^- are compared – with the H^- serving as a proxy for the proton. The BASE collaboration has previously measured this quantity to a precision of 69 ppt [4].

In both property measurements, ω_c is determined by measuring the three eigen-frequencies, $\omega_{+,-,z}$ of the trapped particle and applying an invariance theorem; $\omega_c^2 = \omega_+^2 + \omega_-^2 + \omega_z^2$. The individual eigen-frequencies are accessed by means of non-destructive image currents measurements, using tuned superconducting RCL circuits. A number of technical and methodological improvements have recently been made. The implementation of a new superconducting modified-cyclotron frequency detection system allows direct measurements of ω_+, for both $\bar{\mathrm{p}}$ and H^-. This is in contrast to previous measurements where ω_+ is measured indirectly by coupling axial and modified-cyclotron modes [4]. The addition of a resonance-frequency tunable circuit to the axial detection system, in conjunction with significant improvement to the magnetic field homogeneity, has completely eliminated the principal systematic error of the previous 69 ppt result [4]. Finally, the cryogenic standing time and mechanical stability of the apparatus has been greatly improved. These combined improvements have increased the cyclotron frequency stability, when compared to the previous charge-to-mass ratio measurement, by more than a factor of 5.

An overview of the BASE experiment, measurement principles, and an update on the studies with this considerably improved instrument will be presented.

References

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