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Ultra-High Precision Measurements of the Proton-to-Antiproton Charge-to-Mass Ratio

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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 such property which can be directly measured in Penning traps 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. ω_c is determined by measuirng the three eigen-frequencies, $\omega_{-,z,+}$, of the trapped particle and applying an invariance theorem; $\omega_c^2 = \omega_-^2 + \omega_z^2 + \omega_+^2$. The BASE collaboration has previously measured this quantity to a precision of 69 ppt [4]. This result is consistent with CPT invariance. The proton-to-antiproton charge-to-mass ratio also serves as a test of the weak equivalence principle and can be used to constrain the gravitational anomaly parameter, α_g. The BASE collaboration has constrained this parameter to $|\alpha_g - 1| < 8.7 \times 10^{-7}$ in the case of baryonic matter.

During the current measurement campaign performed by BASE, several 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 contrasts with previous measurements where ω_+ is measured indirectly by coupling axial and modified-cyclotron modes [4]. The addition of a resonance-frequency tuneable circuit to the axial detection system, in conjunction with significant improvement to the magnetic field homogeneity, has eliminated the principal systematic error of the previous 69 ppt result [4]. These new implementations allow the 69 ppt CPT invariance test to be improved upon, and measuring the proton-to-antiproton charge-to-mass ratio at different points in the sidereal year allow improved constraints on the gravitational anomaly parameter.

In this talk preliminary results of the recent proton-to-antiproton charge-to-mass ratio charge to mass ratio campaign will be presented, along with details of the methodologies and improvements used to achieve them.

[1] G. Gabrielse et al., Phys. Rev. Lett., 82, (1999), 3198-3201
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[3] C. Smorra et al., Nature, 550, (2017), 371-374
[4] S. Ulmer et al., Nature, 524, (2015), 196-199

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