Determination of the antiproton-to-electron mass ratio by high precision spectroscopy of $\bar{p}\mathrm{He}^+$ atoms

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ASACUSA collaboration has carried out a laser spectroscopy of antiprotonic helium atoms ($\bar{p}\mathrm{He}^+$: a Coulomb three-body system consisted of an antiproton, electron, and a helium nucleus) at CERN's Antiproton Decelerator facility (AD)[1, 2] and measured transition frequencies of $\bar{p}\mathrm{He}^+$. By comparing the measured frequencies with three-body QED calculations, the antiproton-to-electron mass ratio $m_{\bar{p}}/m_e$ is determined. In 2002, we used a radiofrequency quadrupole decelerator to stop the antiprotons in low density targets and to eliminate a collisional effect with surrounding helium atoms, and determined $m_{\bar{p}}/m_e$ at a level of 10^{-8}. An experimental resolution had mainly been dominated by the linewidth of commercial pulsed dye lasers.

In 2004, we prepared a new laser system to achieve better experimental resolution as follows[3]. A continuous-wave Ti : sapphire or dye laser with the linewidth of 1 or 4 MHz were locked to a femtosecond optical frequency comb with a frequency precision of $< 4 \times 10^{-10}$. The cw laser light was then amplified with a linewidth of ~ 60 MHz in dye cells pumped by a pulsed Nd : YAG laser. A frequency chirp, which was caused by changes in the refractive index of the dye, was actively compensated by using an electron-optic modulator. A residual chirp was measured and corrected by recording a heterodyne beat signal between the amplified laser pulse and a 400 MHz-shifted cw laser light. With the new laser system we improved a fractional precision on the transition frequencies from $\sim 3 \times 10^{-6}$ to $\sim 1 \times 10^{-8}$.

The comparison of the measured frequencies and three-body QED calculations yields the antiproton-to-electron mass ratio of $m_{\bar{p}}/m_e = 1836.152\ 674(5)$. This agrees with the known proton-to-electron mass ratio at the level of $\sim 2 \times 10^{-9}$. A limit on any *CPT*-violating difference between the antiproton and proton charges and masses was also set as $(Q_p - |Q_{\bar{p}}|)/Q_p \sim (m_p - m_{\bar{p}})/m_p < 2 \times 10^{-9}$ to a 90 % confidence level.

References

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