Canadian Association of Physicists

Association canadienne des physiciens et physiciennes

Contribution ID: **279** Type: **Oral (Non-Student) / Orale (non-étudiant(e))**

HAICU: Developing an (anti)hydrogen fountain and quantum interferometer

Wednesday 9 June 2021 15:55 (10 minutes)

Over the last decade, The ALPHA experiment at CERN produced a series of ground-breaking results, having demonstrated the first ever trapping and laser cooling of antihydrogen atoms, and precisely measured many of their physical properties, including the 1s-2s transition and hyperfine splitting. A new ALPHA-g apparatus is being built to precisely measure the gravitational mass of antihydrogen. Comparing these properties with the well-studied hydrogen atom offers a sensitive test of matter-antimatter symmetry, and may yield insight into physics beyond the Standard Model.

The achievable precision of the measurements at ALPHA is, however, limited by the innate magnetic inhomogeneity of the magnetic minimum trap used to confine the anti-atoms (e.g. due to Zeeman splitting). An atomic fountain can help overcome this limit by interrogating the anti-atoms during free-fall in a field-free volume. A practical antihydrogen fountain requires cooling the anti-atoms to micro-Kelvin energies, such that the volume of a free-falling bunch remains small enough for interrogation (usually via a laser or microwave pulse).

This presentation outlines the recent progress made towards the development of HAICU, a next-generation experiment aiming to create a fountain interferometer compatible with both hydrogen and antihydrogen. A sophisticated, superconducting magnetic trap is designed to capture anti-atoms synthesised by mixing antiprotons with positrons, magnetically compress them into a mm-scale volume, cool them using three orthogonal Doppler cooling lasers, transfer them to a large volume trap, adiabatically expand them to achieve micro-Kelvin energies, and finally magnetically launch them into a fountain volume. The radial confinement in the trap system is provided by a novel canted cosine theta (CCT) coil, whose multipole moment changes from octpolar, compatible with the initial synthesis of antihydrogen, into quadrupolar, capable of much stronger radial compression. The transition is achieved while maintaining continuous radial confinement. The strong compression volume is created by four azimuthally offset pancake coils, which are arranged to provide perpendicular optical access to the trap anti-atoms. Magnetic and particle tracking simulation are used to demonstrate the performance of the system, and provide a proof-of-concept for further experimental development work.

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Session Classification: W3-6 Exotic Matter II (DNP) / Matière exotique II (DPN)

Track Classification: Nuclear Physics / Physique nucléaire (DNP-DPN)