Contribution ID: **92** Type: **Talk**

Laser Cooling of Positronium

Thursday 13 June 2024 15:05 (25 minutes)

Positronium (Ps), the short-lived bound state of an electron and a positron, exists for only 142 ns in its parallel-spin ground-state configuration (ortho-Ps). It serves as a crucial testing ground for bound-state Quantum Electrodynamics (QED) and for investigating potential violations of the Weak Equivalence Principle for leptons. Existing experiments and proposed schemes have been limited by the broad velocity distribution of traditional Ps sources. To address this, laser Doppler cooling has been proposed for over 30 years but has not been demonstrated before.

In our research, we conduct the first Ps Doppler cooling experiments within the AEgIS (Antimatter Experiment, Gravity, Interferometry, and Spectroscopy) experiment at CERN's Antiproton Decelerator facility [1]. We employ a custom-built alexandrite laser to cool ortho-Ps along the 13S-23P transition during its brief lifetime. The laser is specifically designed to meet the experiment's demanding requirements, including pulse energies of several mJ in the UV (243 nm) regime, a bandwidth of about 100 GHz, and a pulse duration of about 100 ns with a fast falling edge. Ps cooling is observed by measuring the Doppler broadening of its 1ˆ3S-3ˆ3P line with a second laser immediately after cooling. The estimated temperature of the ensemble of Ps atoms emitting from a nano-porous positron/Ps conversion target decreases from 380 K to 170 K. This corresponds to a decrease in the transversal component of Ps rms velocity from 54 km/s to 37 km/s.

This methodology paves the way for developing unprecedented Ps sources below 10 K with high intensities. It opens avenues for precision spectroscopy and gravitational experiments with Ps and represents a significant step towards achieving the first Bose-Einstein Condensation of an antimatter species.

[1] L. T. Gloggler et al. (The AEgIS collaboration), Positronium Laser Cooling via the 13S−23P Transition with a Broadband Laser Pulse, Phys. Rev. Lett. 132 (2024), 083402, https://doi.org/10.1103/PhysRevLett.132.083402

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Session Classification: Session 8