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Development of a Multi-particle Imager for Exotic Atom Spectroscopy and Interferometry

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Precision spectroscopy of exotic atoms, such as muonium and antihydrogen, is a powerful method for testing the Standard Model of particle physics and searching for new physics beyond it. For example, measurements of the muonium hyperfine structure provide the most stringent tests of bound-state quantum electrodynamics (QED), while spectroscopy of antihydrogen allows for high-precision tests of CPT invariance. However, the precision of measurements involving excited states, such as the muonium Lamb shift, remains at the sub-percent level. This is primarily due to the challenge of detecting the vacuum ultraviolet (VUV) photons (at 122 nm) emitted during atomic de-excitation. Conventional detectors like photomultipliers and microchannel plates (MCPs) have a quantum efficiency of only a few percent for VUV light, making it challenging to distinguish the signal from background events, such as positrons from muon decay. A similar challenge limits non-destructive comparative studies between antihydrogen and hydrogen, and muonium interferometry involving muonium in excited states. To overcome this limitation, we are developing a multi-particle imager specifically designed for next-generation exotic atom experiments. The core of the detector is a "tapered" MCP (T-MCP) combined with a resistive anode encoder. The T-MCP features an optimized surface geometry that achieves high detection efficiency for VUV photons, while the complete imager is designed to distinguish these photons and neutral atoms from charged particle backgrounds and provide position information for each. In this contribution, we present the development status and test beam results.

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