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A cyclotron trap for antiprotonic atom x-ray spectroscopy in gaseous targets

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Quantum electrodynamics (QED) is a foundation of modern physics, whose detailed study is one of the frontiers for Beyond Standard Model searches. In this domain, new physics may appear as minute differences between theory and experiments, accessible with extremely high precision QED tests. While extensive studies have been performed for light systems (hydrogen, antihydrogen, muonic hydrogen, etc.), few high precision measurements exist for high-Z systems with extremely high Coulomb fields.

Decades of work has sought to study this strong-field QED regime via spectroscopy of highly charged ions (HCI) [1, 2]. These systems, however, are plagued by high theoretical uncertainty in the transition energies due to poorly-known nuclear radii, which clouds high-order QED contributions. In order to circumvent such issues, novel studies have been proposed involving exotic atoms, where the orbiting electrons are replaced with a more massive particle, such as a negatively charged muon (μ^-) [3] or antiproton ($\bar{p}$) [4]. In these exotic systems, a special class of Rydberg transitions can be found where QED effects are large, while nuclear uncertainties are negligible, making them prime candidates for high-precision strong-field QED tests [5].

The PAX experiment is a new effort to study Bound State QED (BSQED) in antiprotonic systems, where a range of gaseous elements will be subjected to a low-energy antiproton beam, coming from CERN's Extra Low Energy Antiprotons (ELENA) ring, leading to¯$\bar{p}$ capture in circular Rydberg states, followed by a cascade of Auger and radiative transitions, expelling the remaining electrons and resulting in hydrogen-like antiprotonic systems [4]. In order to assure this, it is necessary to mitigate the electron refilling by using a low-pressure gaseous cell to slow down and capture the antiprotons.

A novel cyclotron trap is currently being designed, with tools such as COMSOL®and GEANT4, in order to be implemented in PAX. Composed of two iron-core coils, the generated magnetic fields of 0.5 T in the interaction region are able to trap the incoming 100 keV antiproton beam, degraded to 10 keV, and slow it down in the process, until capture occurs and the subsequent cascade of x-ray transitions is measured with a state-of-the-art Transition Edge Sensor (TES) detector [6]. Aside from the trap itself, the simulation incorporates realistic particle scattering and
deceleration, as well as the necessary charged particle optics to control a highly dispersive beam.

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