Cosmic Antiproton Sensitivity for the GAPS Experiment

Field Rogers for the GAPS Collaboration

Keywords: GAPS, Antiproton, Dark Matter, Primordial Black Hole, Exotic Atom

The General Antiparticle Spectrometer (GAPS) experiment is a balloon payload designed to measure low-energy (kinetic energy $\lesssim 0.25$ GeV/n) cosmic antinuclei during at least three ~35-day Antarctic flights, with the first flight planned for December, 2022. GAPS is optimized for sensitivity to rare antideuterons, where any detection would be a smoking gun signature of new physics, and will also be sensitive to antihelium-3 nuclei and produce a precision cosmic antiproton spectrum. The GAPS instrument consists of a 10-layer silicon tracker surrounded by a time of flight system. GAPS relies on a novel exotic atom-based method for particle identification, in which a negatively charged antinucleus slows down within the detector before being captured into an exotic atom. The exotic atom de-excites via X-rays before annihilating in a star of secondary particles. The exotic atom signature is unique to negatively charged particles, and the energy deposition patterns, X-rays, and secondary particle multiplicity identify the antincleus species. With this exotic atom-based particle identification, GAPS does not require a pressure vessel, cryostat, or magnet, which facilitates its large acceptance for rare antinuclei within the constraints of a balloon payload.

With high statistics in a measurement extending to lower energy than any previous experiment, and with orthogonal sources of systematic uncertainty compared to measurements made using traditional magnetic spectrometer techniques, the GAPS antiproton measurement will be sensitive to physics including dark matter annihilation, primordial black hole evaporation, and cosmic ray propagation. The antiproton measurement will also validate the GAPS exotic atom technique for the antideuteron and antihelium rare-event searches and provide insight into models of cosmic particle attenuation and production in the atmosphere. This contribution demonstrates the GAPS sensitivity to antiprotons using a full instrument simulation with event reconstruction, and considering solar and atmospheric effects.

The main challenge for the GAPS antiproton measurement is the high fluxes of background nuclei at float altitude. Protons, the most abundant background species, must be rejected at $>10^6$ relative to antiprotons. While positively charged nuclei cannot produce exotic atoms, some produce secondaries via hard interactions in the detector and can mimic the exotic atom signature. Due to the immense fluxes of protons, this is an important background to antiprotons in our analysis. We developed several event variables to reject particles with charge greater than 1 and to probe kinematic differences between secondaries produced in hard interactions as opposed to exotic atom annihilation. We used a likelihood analysis to achieve relative acceptance of $<10^{-6}$ for protons relative to antiprotons while maintaining the high signal acceptance required for a precision cosmic antiproton spectrum.