Reconstruction of antinucleus-annihilation events in the GAPS experiment

The General Antiparticle Spectrometer (GAPS) experiment is designed to detect low-energy (< 0.25 GeV/n) cosmic-ray antinuclei as indirect signatures of dark matter. Several beyond-the-standard-model scenarios predict a large antideuteron flux due to dark matter decay or annihilation compared to the astrophysical background. The GAPS experiment will perform such measurements using long-duration balloon flights over Antarctica, beginning in the 2022/23 austral summer. The experimental apparatus consists of ten planes of Si(Li) detectors surrounded by a time-of-flight (ToF) system made of plastic scintillators. The detection of the primary antinucleus relies on the reconstruction of the annihilation products: the low-energy antinucleus is captured by an atom of the detector material, forming an exotic atom that de-excites by emitting characteristics X-rays. Finally, the antinucleus undergoes nuclear annihilation, producing a “star” of pions and protons emitted from the annihilation vertex.

Two algorithms have been developed to determine the annihilation vertex position and to reconstruct the topology of the primary and secondary particles: an algorithm based on the Hough-3D transform and a custom algorithm specifically developed for this experiment (“Star Finding”). In the Star Finding algorithm the track of the primary antinucleus is identified from the first hits in the ToF, then other consistent hits are added to the track. A scan is then performed along the extrapolation of the primary track to find the best annihilation vertex position candidate and the secondary tracks originating from it. The position is chosen to maximize the number of hits intersected from the minimum number of trajectories originating from it: the found trajectories are identified as the secondary tracks. The final vertex position is then estimated minimizing its distance from all the reconstructed tracks. The algorithm is finally iterated again after some quality selection cuts on reconstructed tracks and hits. The obtained reconstruction efficiency with the Star Finding algorithm is ~90%, the distribution of the vertex position resolution has a peak around 1 cm and 68% of the events fall within 9-12 cm. The Hough-3D algorithm shows instead worse performances (75% efficiency, resolution peaked at ~1.3 cm and with a 68% containment within ~14 cm). Reconstruction performances satisfy the requirements for the discrimination between different antinuclei. As an example, a vertically incident antideuteron with $\beta < 0.4$ stops more than 12 cm deeper in the tracker with respect to an antiproton with comparable velocity.