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Reconstruction algorithms for identification of cosmic rays antinuclei with the GAPS experiment

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Summary. — The General Antiparticle Spectrometer (GAPS) is a balloon-borne detector designed to measure low-energy (<0.25 GeV/n) antideuteron cosmic ray component as a low-background signal from dark matter annihilation or decay in the Galactic halo. The detector consists of a tracker, made up by ten planes of lithium-drifted silicon detectors, surrounded by a plastic scintillator time-of-flight (ToF) system. GAPS uses a novel technique for particle identification based on the formation and decay of exotic atoms. Here we present preliminary results for two reconstruction algorithms, one based on a classical approach and one on a deep learning approach, that have been tested on simulated events.

1. – Introduction

The decay or annihilation of Dark Matter (DM) particles in the Galaxy could contribute to Cosmic Ray (CR) fluxes. The GAPS instrument is specifically designed to detect low-energy cosmic antinuclei: possible DM decay products with low astrophysical backgrounds.

The predicted flux of DM-produced cosmic antideuteron below few GeV/n is several orders of magnitude above the expected flux of deuterons from astrophysical origin (*i.e.*, from secondary interactions of cosmic rays). Figure 1 (left) shows representative antideuteron spectra predicted from several DM models (see [1]).

GAPS uses a novel particle identification method based on the capture of an antinucleus by a nucleus in the detector to form an exotic atom in an excited state. This de-excites, emitting X-rays, before annihilating with production of pions and protons.

(*) `gaps1.astro.ucla.edu/gaps/authors/alist.html`

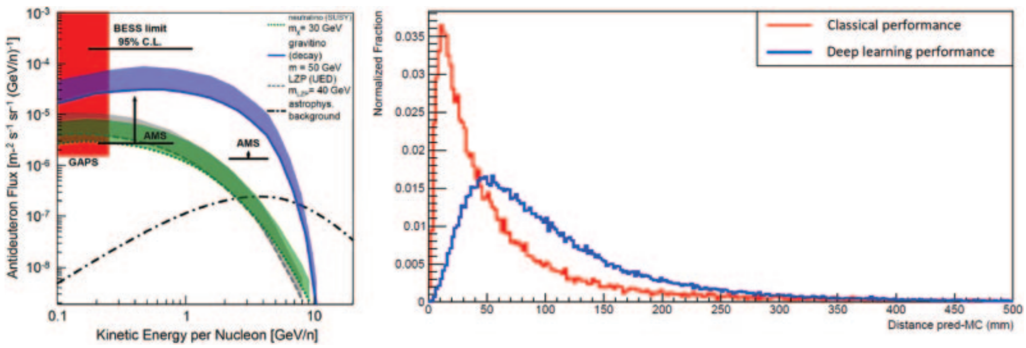

Fig. 1. – Left: predicted primary antideuteron spectra at the top of the atmosphere from various dark matter models, shown with the BESS limit and predicted sensitivities for GAPS and AMS-02. Right: a comparison between the performance of the classical and deep learning algorithms in terms of Euclidean distance of the reconstructed vertex from the Monte Carlo vertex.

This unique "annihilation star" topology provides rejection power against the CR background, while the X-ray energies, hadron multiplicity, and incident particle-track signatures distinguish between different antiparticle species. For more details on the scientific motivations and the GAPS apparatus, see [2].

2. – Reconstruction technique

The goals of the reconstruction algorithm is to evaluate the quantities needed to perform the antinuclei identification; in particular, $\beta = \frac{v}{c}$ of the primary, the location of the annihilation vertex, and the multiplicity of secondary tracks from the vertex. The algorithm has been developed within the framework of the GAPS simulation that fully reproduces the instrument geometry materials and is based on GEANT4.

The primary trajectory is reconstructed using a track finding approach assuming the initial direction defined by the first two hits measured by the umbrella and cube ToF. Possible additional hits satisfying spatial and energy consistency are associated to the primary track (see [3]). Secondary tracks are identified using the Hough transform algorithm, which associates points that lie in a common direction. Finally, the annihilation vertex position is the point which minimizes the deviation among all the reconstructed tracks. A deep learning approach which makes use of Convolutional Neural Networks was also applied as an independent algorithm for the vertex finding problem. This method has an higher efficiency and faster execution time at the cost of some precision. Figure 1 (right) compares the performance of the classical and deep learning algorithms.

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