Journal of Physics: Conference Series

PAPER • OPEN ACCESS

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To cite this article: S A Rodenko *et al* 2019 *J. Phys.: Conf. Ser.* **1189** 012009

IOP Conf. Series: Journal of Physics: Conf. Series **1189** (2019) 012009 doi:10.1088/1742-6596/1189/1/012009

Track reconstruction of antiprotons and antideuterons in the coordinate-sensitive calorimeter of PAMELA spectrometer using the Hough transform

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Abstract. A method for identifying antiparticles (antiprotons and antideuterons) of low energies in the sampling imaging electromagnetic calorimeter in the PAMELA experiment is proposed. Tracks of antiparticles before annihilation in detector medium, as well as tracks of secondary particles that were born in the annihilation process, were identified using the Hough transform, the digital image processing method which allows us to search for straight lines on images, which in this case are tracks of particles and antiparticles (searching for the "star" topology).

1. Introduction

Detailed measurements of antiproton flux variations in the cosmic rays are important for solving many fundamental cosmophysics challenges as well as for some applied tasks. Searching for antideuterons also would be valuable to solve these tasks.

For precise measurements of antiparticles fluxes (including searching for antideuterons) the magnetic spectrometer PAMELA was designed by international science collaboration [1]. The instrument was installed on the board of Russian satellite Resurs-DK1, which has been launched in 2006 year. Continuous data acquisition had been taken place from July 2006 to January 2016. The PAMELA spectrometer's detectors set allows to register and identify type of registered particle with a good confidence level, and more valuable it has a possibility to register and identify an event with different subsets of detectors independently, performing cross-check.

For example, magnetic tracking system, designed to separate particles of different sign of charge and measure rigidity by magnitude of a particle deflection in magnetic field was used to select antiprotons in energy range 80MeV - 350 GeV in works [2] and [3]. In low part of the energy range (100 - 500 MeV) the results can be crosschecked and enhanced by increasing statistics using the PAMELA's sampling imaging electromagnetic calorimeter.

Antiparticles of the indicated energy range is slowing down inside the calorimeter losing energy according to Bragg law till point of stop, where they annihilate with the Calorimeter material, resulting in large energy release and production of secondary particles, mostly pions. A detector response on it is an pixelized image in two projections XZ and YZ, where Z - is the Instrument's main axis, a color depicts energy release in a strip. Hitted strips form a trajectory of particles or antiparticles in the calorimeter. Using Hough transformation to analyze image to find out straight lines (tracks) it's became possible to develop the method of annihilating antiparticles tracks reconstruction for the antiparticles stopping in the Calorimeter and their identification on the other particles background.

2. Hough transform

The Hough transform is a technique used in image analysis and computer vision, which can identify lines or other forms on a digital image. In the simplest case, it based on a transition to a new space with other parameters, where the search for lines is trivial. Consider the parametric equation of the straight line:

$$\rho = x \cdot \cos\theta + y \cdot \sin\theta \,, \tag{1}$$

where ρ is the distance (length of the radius vector) from the origin to the closest point on the straight line (that is the normal to the line drawn from the origin), and θ is the angle between the x axis and the line connecting the origin with that closest point (this vector), see Figure 1 left panel.

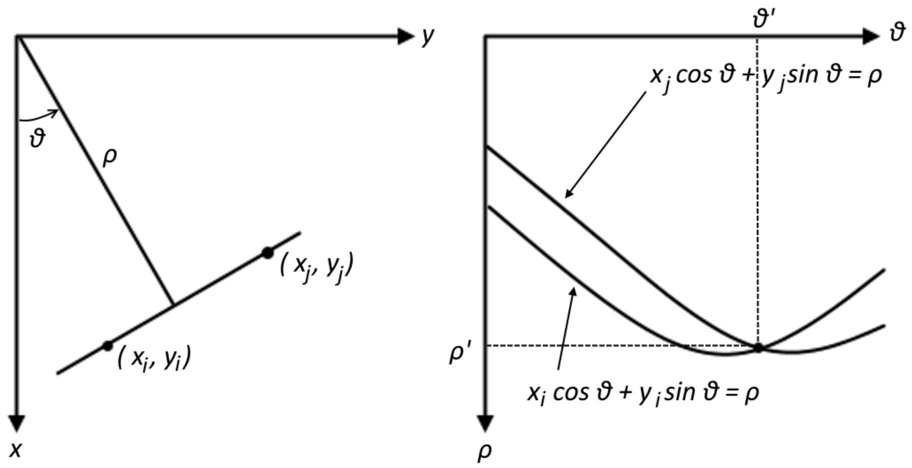

Figure 1. Straight line in X-Y parameter space (left) and in ρ-θ parameter space (right).

Let's fix two points (x_i, y_i) and (x_i, y_i) on the straight line and transform them into the parameter space (θ, ρ). Each of the points in the original image goes into a sin function. Then the line in the X-Y space will transform to the intersection point of the sin functions in the θ-ρ space as it shown on figure 1, right panel. With each straight line in the original image it can be associated a single point with the coordinates (θ', ρ'), which is unique, provided that $\theta \in [0, 2\pi]$ and $\rho > 0$ [5].

Finding the intersection point of the sin functions allows to determine the equation of the straight line (1).

3. Method

The isotropic flux of antiprotons and antideutrons with rigidities from 0.5 to 5 GV and their propagation thought the PAMELA spectrometer were simulated with the software based on the Geant4 package (model FTFP_BERT with the standard model of electromagnetic interactions) [7].

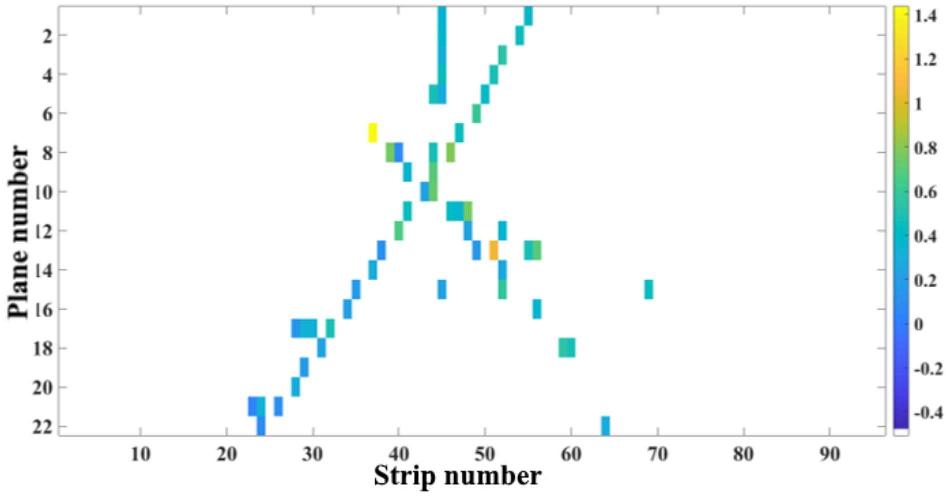

Figure 2. An interaction of antiproton with rigidity -0.7 GV inside the calorimeter.

An algorithm for particle's track identification consists of following items:

- Transformation of the image of particles interaction inside a calorimeter into a binary image;
- Application of the Hough transform to the resulting binary image and search for a set of straight lines;
- Classification of this lines to the groups corresponding to primary (antiproton or antideuteron) and secondary particles (mesons);
- Identification of the track corresponding to the primary antiparticle.

Let's demonstrate the algorithm on example - an antiproton with a rigidity of -0.7 GV. Figure 2 shows the image of its annihilation inside the calorimeter: the X axis is a number of strip and the Y axis is the number of plane, the color shows the energy release (the brighter color corresponds to the higher energy release). This image transform to a binary one, assuming that the absence of a signal is a logical zero, and the presence of energy release is a logical unit (figure 3).

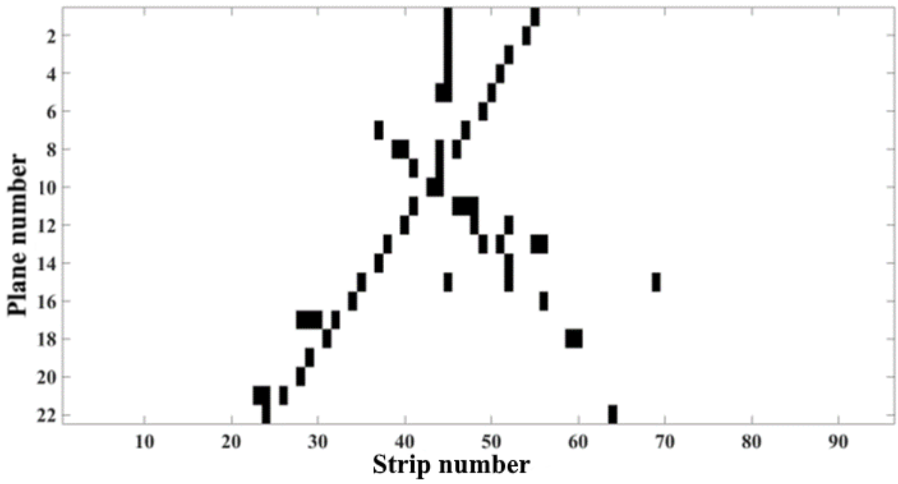

Figure 3. Binary image of antiproton interaction inside the calorimeter

We apply the Hough transform to the parameter space (θ, ρ). The distribution of the strips in this plane is shown in Figure 4: the shades of gray show the number of intersections of sinusoids in fractions of a unit; the darker, the more intersections.

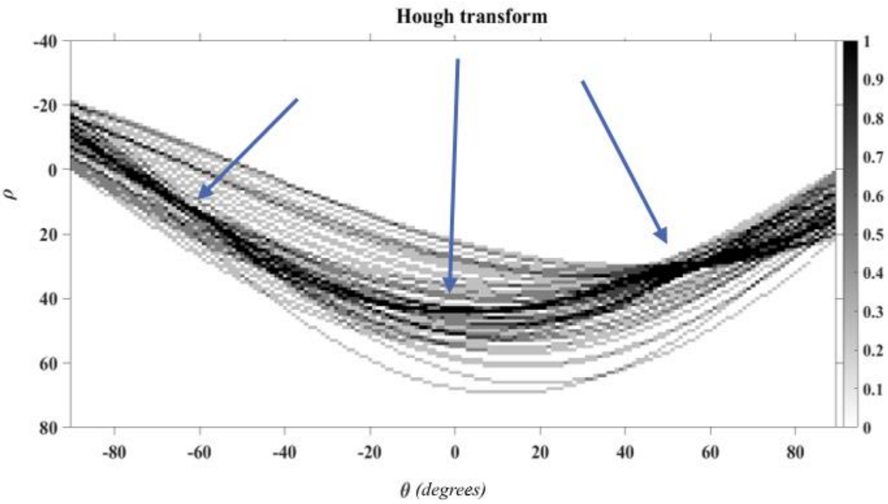

Figure 4. Hough transform in (θ, ρ) parameter space

The darkest regions correspond to the greatest number of intersections of the sin functions, and hence to the lines in the original image. All found lines are shown in green in Figure 5, most of them corresponds to angles of about ± 60° and 0°.

K-means clustering is used to link the found lines to the various particles. The signs of the k-means clustering is the slope of the line and its starting point. According to signs, the classifier distributes lines, which in their topology refer to primary and secondary particles. In this case, the track of the primary particle is a track coming from the main aperture of the device.

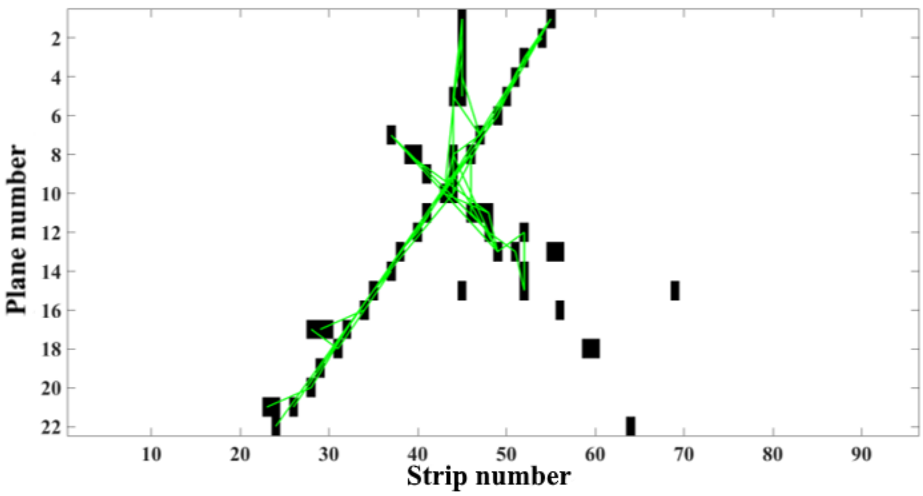

Figure 5. All reconstructed tracks for primary and secondary particles.

In Figure 6, the red line shows the track reconstructed in the calorimeter corresponding to the track of the primary antiproton. The energy of the antiproton can be determined by analyzing the mean free path and the energy release to the stopping point (the Bragg curve).

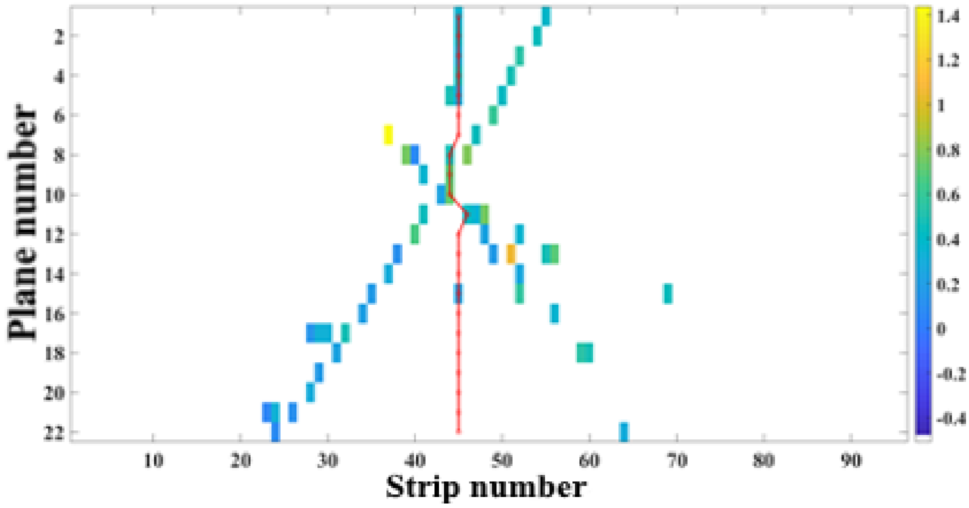

Figure 6. The track reconstructed in the calorimeter.

4. Conclusion

The developed technique can be used to reconstruct tracks of antiprotons and antideutrons, which allows to identify these low-energy antiparticles with the help of the PAMELA's sampling imaging electromagnetic calorimeter. The quality of the technique will be further evaluated using Monte Carlo simulation and in case of good indicators it will be applied to the experimental data.

Acknowledgments

This work was supported by Russian Ministry of Education and Science in frame of project № 3.2131.2017.

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