

Verification of charge sign for high-energy particles measured by magnetic tracking system of PAMELA spectrometer

A D Lukyanov^{1,3}, V V Alekseev¹, Yu V Bogomolov¹, O A Dunaeva¹,
V V Malakhov², A G Mayorov^{1,2} and S A Rodenko²

¹ Department of Physics, Yaroslavl State P.G. Demidov University, 150000 Sovietskaya st., 14, Yaroslavl, Russia

² National Research Nuclear University MEPhI, 115449 Kashirskoe shosse 31, Moscow, Russia

E-mail: anton.lukyanov@gmail.com

Abstract. Analysis of experimental data of primary positrons and antiprotons fluxes obtained by PAMELA spectrometer, recently confirmed by AMS-02 spectrometer, for some reasons is of big interest for scientific community, especially for energies higher than 100 GV, where appearance of signal coming from dark matter particles is possible. In this work we present a method for verification of charge sign for high-energy antiprotons, measured by magnetic tracking system of PAMELA spectrometer, which can be imitated by protons due to scattering or finite instrumental resolution at high energies (so-called “spillover”). We base our approach on developing a set of distinctive features represented by differently computed rigidities and training AdaBoost classifier, which shows good classification accuracy on Monte-Carlo simulation data of 98% for rigidity up to 600 GV.

1. Introduction

There are natural restrictions when measuring energy of particles in any tracking system: finite spatial resolution and possible scatterings in detector’s material. Sometimes it results not only in error of energy measurement, but also in error of charge sign identification (see figure 1) and with energy increase it happens more frequently. This effect is often called “spillover” when proton can be mistakenly identified as antiproton or electron as positron (and vice versa). Spillover can significantly affect measurement results of particles fluxes especially if analyzed flux component is considerably smaller and should be carefully considered.

PAMELA is the experiment conducted between June 2006 and January 2016 at near-Earth orbit on Resurs DK1 satellite and based on magnetic spectrometer including tracking system ([1]). Since 2006 a number of interesting scientific results and several scientific discoveries have been made by the present time ([2], [3], [4]).

Processing of experimental data is still continuing, although a lot of measurements of positron and antiproton fluxes obtained in PAMELA experiment have been already confirmed in AMS-02 experiment. Hence it became interesting to move to the area of higher energies (higher than several hundreds GV), where spillover effect appears.

³ To whom any correspondence should be addressed.



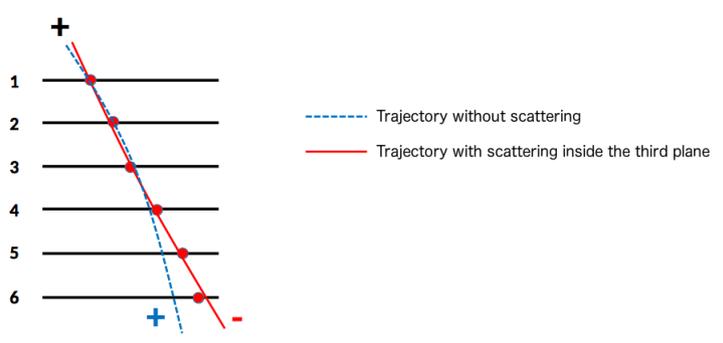


Figure 1. Example of particles trajectories with and without scattering.

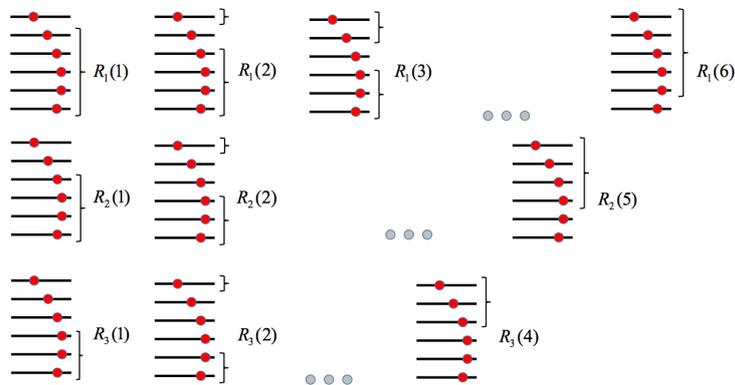


Figure 2. Refitted rigidities.

We developed a method for identification of antiprotons and tested it using simulation of particles passing through spectrometer generated by software package in Geant4 environment used by PAMELA collaboration. We simulated events (protons and errors) with true rigidities $R_t \in [50, 1000]$ GV. Our goal is to tell using a set of distinctive features whether an events is error or not. Errors may appear as a result of scattering inside tracking system detector's material or due to finite spatial instrumental resolution (see figure 1). Since there are approximately 10^4 times more protons than antiprotons each error may greatly increase the flux of antiprotons. We would like to suppress spillover and obtain better results in the area of high energies compared to the results published before.

2. Distinctive features and our approach

Our approach consists in developing a set of distinctive features and training classifier to separate them. We model tracking system events with Geant4 and compute the following features based on track of a particle as shown in figure 2. Each feature $R_i(j)$ represents a rigidity which is computed using original track, but by excluding i points from track and a cyclic shift by j positions. Resulting features are quite distinctive and show low pairwise correlation (see figure 3).

3. Classification results

We use AdaBoost (or Adaptive Boosting) classifier [5] on Decision Trees. It is a classification meta-algorithm: it combines weak classifiers w_t (in our case decision trees) so that each consequent weak classifier focuses on objects misclassified by previous learners and represents

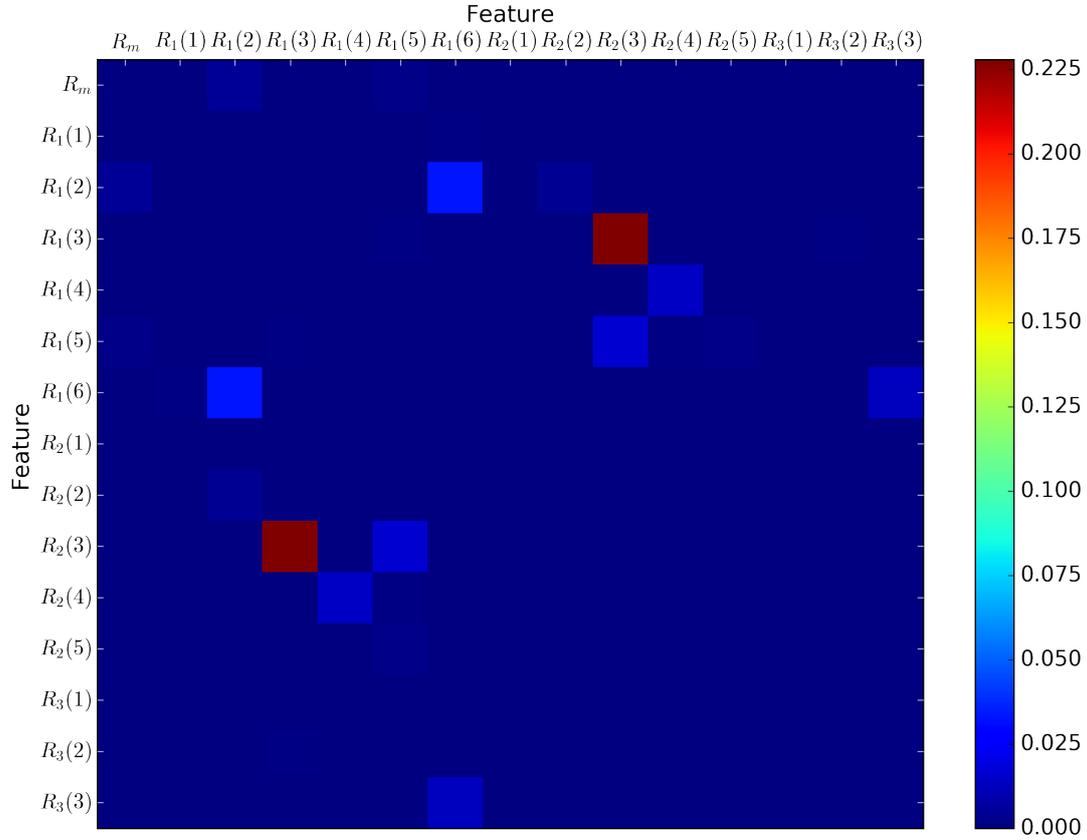


Figure 3. Correlation map (absolute values) between computed features.

Table 1. Classification results for $X = 1000$ and $X = 1200$. True classes are rows and predicted classes are columns.

$ R_m > 1000$		
	proton	error
proton	68241 (84.74%)	12287 (15.26%)
error	9 (0.11%)	8044 (99.89%)

$ R_m > 1200$		
	proton	error
proton	71020 (88.19%)	9508 (11.81%)
error	7 (0.09%)	8046 (99.91%)

final classifier as a weighted sum:

$$C(x) = \text{sign} \left(\sum_{t=1}^T \alpha_t w_t(x) \right).$$

AdaBoost is a special case of gradient boosting with exponential loss function [6].

We train classifier two different ways:

Table 2. Classification results using AdaBoost. True classes are rows and predicted are columns.

	proton	error
proton	79201 (98.35%)	1327 (1.65%)
error	34 (0.42%)	8019 (99.58%)

1. In the first approach during testing we impose some bounds on $|R_m|$ and mark events for which $|R_m| > X$ as errors. It allows classifier to focus on separation of protons and errors in a range $R_m \in [0, X]$. Number of misclassified errors grows with the bound X on R_m . Results of classification can be seen in table 1. Misclassified errors rigidities R_m for $X = 1000$ GV are between 460 GV and 970 GV; for $X = 1200$ GV misclassified error rigidities are between 460 GV and 1050 GV. Therefore we can accurately identify charge sign (with probability of 88%) with energy up to 460 GV on the protons background if their fraction exceeds $3.75 \cdot 10^{-5}$ at 95% confidence (expected much higher fraction is about 10^{-4}).
2. In the second approach we do not impose any bounds on $|R_m|$, split data into training and testing sets and train AdaBoost classifier. Results of classification can be seen in table 2. Despite the fact that there are more misclassified errors, they all have rigidity higher than 600 GV and we still can identify particle charge sign below this level at 98% accuracy.

4. Conclusion

In this work we presented an application of classification algorithm for verification of particle charge sign measured by PAMELA spectrometer. We showed that by using Monte-Carlo modelling in Geant4 environment it is possible to accurately identify charge sign for rigidity up to 600 GV if there are 6 coordinates of a trajectory inside the tracking system in a deviating projection. This result will allow us to move to the area of higher energies in the experiment, in particular, when measuring fluxes of antiprotons and positrons. In the future we plan to test this approach for events with trajectories consisting of 5 coordinates.

5. Acknowledgements

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