New method of electrons and protons separation in the calorimeter of the PAMELA instrument

S O Kleymenova*, V V Mikhailov

National Research Nuclear University MEPhI (Moscow Engineering Physics Institute), Kashirskoe highway 31, Moscow, 115409, Russia.

E-mail: *somebodysom@mail.ru, vvmikhajlov@mephi.ru

Abstract. The PAMELA experiment on board the Resurs DK satellite was equipped with electromagnetic imaging calorimeter which comprises 44 silicon planes interleaved with 22 plates of tungsten absorber (total depth 16.3X0). High granularity of calorimeter allows an accurate spatial reconstruction of the shower development. New method of separation of electrons and protons based on single strip distribution outside of main particle track is discussed. Monte-Carlo simulation shows that by adding this method the proton rejection power of the instrument can be increased several times in energy range from 1 up to ~200 GeV.

1. Introduction

The PAMELA is space experiment designed to measure the spectra of antiparticles in high-energy cosmic radiation. The main research objectives of the experiment: an investigation of dark matter; a study of the composition and propagation of cosmic rays; an exploration of solar rays and solar modulation [1].

On the 15th of June 2006, the PAMELA experiment was launched onboard the Resurs-DK satellite. The instrument consists of (from top to bottom): a set of time-of-flight scintillators (ToF); a magnetic spectrometer with microstrip silicon tracker; an anticoincidence system; a 16 radiation length thick electromagnetic calorimeter, shower scintillator and a neutron detector. The apparatus can be seen in figure 1.

The calorimeter of the PAMELA instrument consists of 22 tungsten plates, each of them is located between the two silicon strip plates. Each Si detector plane is formed by an array of 3 × 3 square sensors of area 8 cm × 8 cm; on each sensor 32 strips are implanted with 2.4 mm pitch. The 9 sensors of a plane are arranged in 3 ladders thus giving total 32 × 3 = 96 read-out channels per plane. The strips in adjacent planes are oriented perpendicular to each other. This fact allows obtaining two projections for the data and building spatial pattern of shower [1].

The one of main task of the calorimeter is to select positrons and antiprotons from proton and electron backgrounds respectively, which are significantly, 10³ times, more abundant in cosmic ray. The parameters of hadronic and electromagnetic showers in the calorimeter such as the initial development point, the longitudinal and transverse shower profiles, the maximum of the energy released in single strips were used to distinguish positrons and antiprotons against the background of protons and electrons respectively [2].

The calorimeter also performs an independent measurement of the energy of the incident electron or positron that can be cross-checked with the momentum measurement operated by the magnetic
spectrometer [1]. With these characteristics it was shown [2] that the calorimeter is able, for known particle rigidity greater than ~ 1 GV, to discriminate positrons from the proton background with a rejection factor of more than $10^5$ (not more than one p out of $10^5$ may be identified as positron) at a selection efficiency for positrons of more than 90%. Meanwhile performance of the instrument was varying with time during the experiment and it is important to study its maximum rejection power.

![Figure 1](image1.png)

**Figure 1.** (left) An electron event with energy 56 GeV. The bending (x) view is shown. The particle passed the TOF system, magnetic spectrometer and finally interacted in the calorimeter. The calorimeter shows the electromagnetic shower. (right) A proton event with the same energy. The calorimeter shows the hadron shower.

2. Analysis
A primary particle crossing the W absorber layers of the calorimeter can produce a cascade (or shower) of secondary particles, which release energy by ionization in the Si detectors. The electromagnetic shower produced by electron or positron and the hadronic shower generated by a proton or antiproton are characterized by different interaction mechanisms.

The electromagnetic shower caused by an initial bremsstrahlung process with emission of a high-energy photon, this photon can then annihilate into a new high energy electron-positron pair which can produce again bremsstrahlung and so on, with the creation of a large number of secondary $e^\pm$ and photons. The number of particles in the shower reaches a maximum value when the average fraction of primary energy carried by the secondary particles approaches the critical energy (about 8 MeV for W), below which the ionization energy loss becomes the dominating mechanism of interaction for $e^\pm$ and the Compton scattering for photons. On the other hand the hadronic shower produced by incident protons is initiated by an inelastic nuclear interaction causing the excitation and fragmentation of a nucleus of the absorber material, with subsequent nuclear interactions of the recoiling fragments and production of high energy pions. Neutral pions can initiate electromagnetic cascade. Charged pions can bring energy far from point of initial interaction. Consequently, the transverse momentum of the secondary particles is larger and hadronic shower is more spread [3].
Differences in spatial development of electromagnetic and hadronic showers are demonstrated in figure 1 which shows examples of Monte-Carlo simulations of electron and interacting proton events with energy 56 GeV. Due to different origin electromagnetic and hadronic interactions, strips far from shower axis also may contain information about initial particle.

We studied number of the single hit strips and number of sequentially hit strips in each plane. Then total numbers of single strips and strips with neighbors were summed in the calorimeter for all planes and for both projections. Then value $K$ was calculated using the formula:

$$K = \frac{n - s}{n + s}$$

where $n$ – the total number of strips into groups, $s$ – the total number of single strips. This value can be used for additional proton rejection.

MonteCarlo simulations were performed for electrons and protons with energy from ~1 GeV till ~300GeV to study behavior $K$ parameter with energy. For simulation standard the PAMELA collaboration program GPAMELA was used [1].

![Figure 2. Distribution on K parameter. Energy = 11.3 GeV.](image1)

![Figure 3. Distribution on K parameter. Energy = 200 GeV.](image2)

### 3. Results

In figures 2 and 3 the examples of $K$ parameter distribution for electrons and protons are shown for energies 11GeV and 200GeV respectively. In case known total energy clear separation of electrons and protons is visible from figures.

For electrons the fraction of grouped strips are always high and it is increasing with energy. Distribution of $K$ parameter has only one peak which lies in interval from -0.15 to 0.4 in our simulated energy range.

Because the PAMELA calorimeter is thin (it has only ~0.6 nuclear interaction length) the probability that a hadronic showers generated by an incoming protons undergoing an inelastic nuclear interaction is approximately $1 - \exp(-0.6) \sim 45\%$. Most of protons pass calorimeter releasing energy only for ionizations and so they hit only one strip per plane. In this case parameter $K$ is negative and closes to -1. For low energies ($E < \text{several tens GeV}$) of interacting protons the pion multiplicity is still small to produce dense hadronic shower. Those interacting protons produce a spread tail of
distributions in figure 2. Parameter K increases in case interaction of high energy proton (figure 3, right peak).

Figure 4 shows threshold value of K parameter as function of energy for 90% efficiency of electrons selection (left) and rejection factor of protons (right) with using this method. In the experiment total particle energy can be obtained from measurements of charge and rigidity with magnetic spectrometer. So new method might improve positron selection of the PAMELA calorimeter because it is used additional information and one can expect low correlation with previously used parameters.

4. Conclusion

1) Rejection factor about $10^2$ was obtained using proposed method for PAMELA calorimeter. In the energy range from 10 to 18 GeV it is reaches $10^3$.
2) New method might improve positron selection of the PAMELA instrument at high energies.

![Graph](image)

**Figure 4.** A) (left) Threshold value of K parameter as function of energy. B) (right) Rejection factor of protons as function of energy.

References

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