Measurement of cosmic rays positron-electron spectrum with electromagnetic calorimeter of PAMELA instrument

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***Abstract*. The description of identification method of high energy electrons with the calorimeter of PAMELA satellite experiment is presented. The method provides selection and energy measurement of electrons and positrons in energy range from tens of GeV up to one TeV. Developing of this method is necessary for energy range above 300 GeV where measurements by magnetic spectrometer are impossible. This energy region is of particular interest as positron-electron spectrum above 100 GeV can have signatures from cosmological processes like dark matter particles annihilation or generation in the near-by pulsar magnetospheres. Preliminary spectrum obtained shows a quite good agreement with data of other experiments.**

***Keywords*: electrons, high energy, calorimeter**

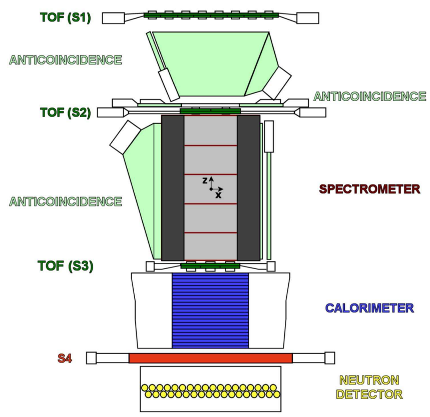

Fig. 1: A schematic view of the PAMELA apparatus.

I. INTRODUCTION

PAMELA has been mainly conceived to carry out high-precision spectral measurement of antiprotons and positrons and to search for antinuclei, over a wide energy range. Precise measurements of electron spectrum up to TeV energy range is foreseen as well.

The PAMELA apparatus comprises the following detectors, arranged as shown in Figure 1 (from top to bottom): a time-of-flight system (TOF – S1, S2, S3); a magnetic spectrometer; an anticoincidence system (CARD, CAT, CAS); an electromagnetic imaging calorimeter; a shower tail catcher scintillator (S4) and a neutron detector. The acceptance of the spectrometer, which also defines the overall acceptance of the PAMELA experiment, is 21.5 cm^{2}sr.

An electromagnetic calorimeter (16.3 X_0, 0.6 λ_0) consists of 22 equal tungsten layers interleaved by 2 layers of silicon detectors with 2.4 mm strips. Strips in each 2 neighbor silicon layers are perpendicular. The calorimeter allows to reconstruct 3D image of particle interaction in its volume. It measures the energy of incident electrons and allows topological discrimination between electromagnetic and hadronic showers or non-interacting particles.

More technical details about the PAMELA instrument can be found in [1].

II. METHOD OF HIGH ENERGY ELECTRONS IDENTIFICATION

Tracking system of PAMELA spectrometer can provide a reliable measurement of momentum of particle up to several hundred of GeV (value of MDR is 740 GeV [2]). So for studying of high energy range of cosmic ray spectrum (above several hundreds of GeV) only a calorimeter [3] can be used. Particle identification should be provided only by using the information from the calorimeter as well as its energy measurement.

Developed method allows selection of electrons and positrons and their energy measurement from ~20 GeV up to ~1 TeV. Method was developed by using Monte-Carlo (MC) data simulated with official program of simulation of the instrument of PAMELA collaboration GPAMELA based on GEANT3 and on packet of hadron processes simulation GHEISHA.

Electrons with energies 20 GeV and more produce quite strong showers. So for further analysis only well developed showers in the calorimeter are interested.

For electrons total energy deposit is correlated with a number of hitted strips. So making a cut on these parameters it is possible to avoid non interacting particles or showers started deep in the calorimeter. Now for selection of electrons from rest of the showers it is necessary to reconstruct an axis of the shower to be able to calculate topological parameters of selection. Reconstruction of axis is implemented by using least squares fit method on centres of gravity of energy releases in a number of planes. Because electromagnetic showers are more regular than hadronic ones accuracy of shower axis reconstruction of electro-magnetic shower is higher. It leads to lower values of χ^2 that allows to suppress protons at this stage of selection.

Since shower axis is found fraction F_{E26} of energy deposited in a cylinder of 0.5 Molier radius in planes X and Y from 2nd to 6th is calculating. Distributions of

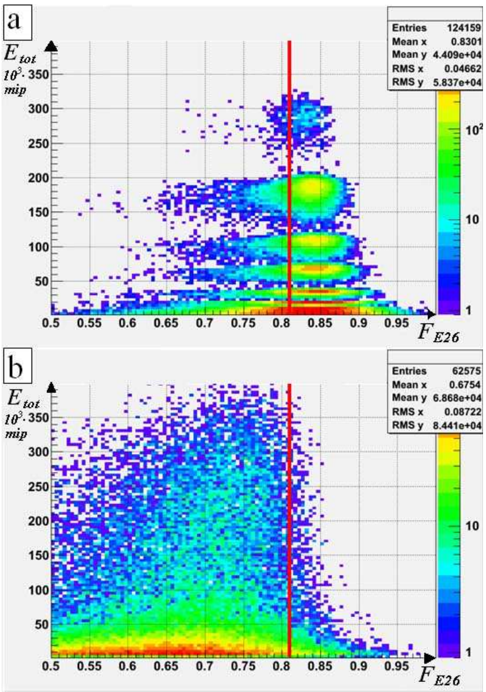

Fig. 2: Distributions of parameter F_{E26} and corresponding efficiencies.

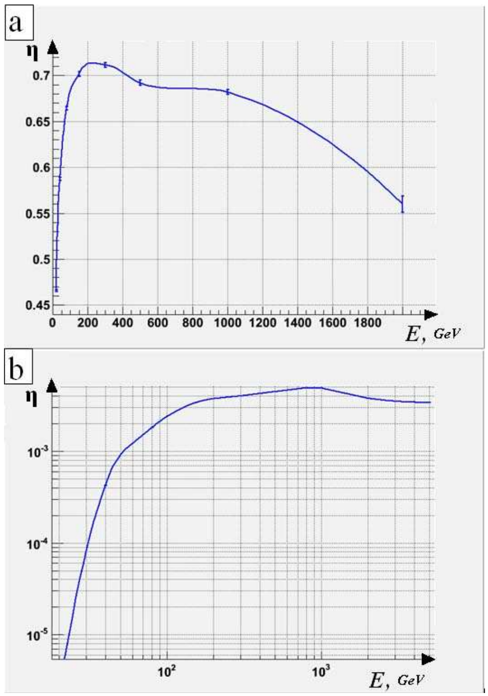

Fig. 3: Distributions of parameter F_{E26} and corresponding efficiencies.

electron and proton events on this parameter in figure 2a and 2b are presented. It was found that it is optimal to select events with value F_{E26}>0.81. This is a very powerful criterion because after its application only 0.5% of protons is remaining while efficiency of electron selection is near 70% almost in all energy range of interest (see figure 3a and 3b).

Further for suppression of hadronic component of cosmic rays criteria on shower starting point and its homogenity are used. They allow to reach a proton rejection at level $10^3 - 10^4$ and efficiency of electron selection at level of 50% – 60% almost in all energy range of interest – see figure 4c and 4d. Electron selection efficiency in whole energy range was fitted by a single smooth function that allows to reconstruct spectrum without jumps and breaks.

Measuring of electron energy based on total energy release in the calorimeter was used. Energy resolution was roughly 10%. In case of full shower containment inside the calorimeter dependence between total energy deposited and initial energy of electron is linear, but if part of the shower is escaping from the calorimeter nonlinear correction is needed. In energy range of interest introduction of the 2^{nd} order polinom correction is sufficient.

Using method described above a common electron-positron spectrum from 26 GeV to 1100 GeV was obtained. Obtained spectrum is in agreement with previous experimental data. To be sure that developed method works correctly the checks with magnetic spectrometer data were done.

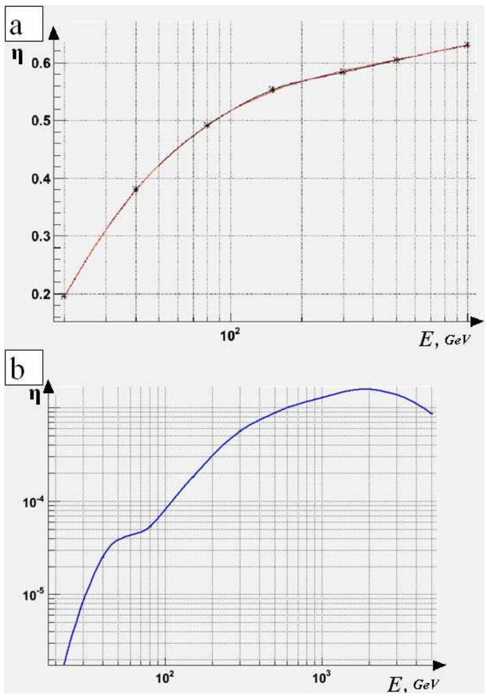

Fig. 4: Final efficiencies of proton and electron selection.

III. CHECKS OF THE METHOD

Fraction of imitations was estimated. As proton-electron ratio in cosmic rays increases from $\sim 10^2$ for energies $\sim$10 GeV to $\sim 10^3$ for energies $\sim$1 TeV while a proton rejection power is decreasing from $\sim 10^5$ to $\sim 10^3$ the estimation of proton contamination was done especially for high energies. It was found that protons imitating electron showers has an energy roughly 3 times higher than electrons that has the same total energy deposition in the calorimeter. It means that effective proton-electron ratio decreasing roughly 20 times (spectral index of protons is -2.7 and with increasing of energy in 3 times the flux of particles is decreasing in $3^{2.7}\approx 20$ times). Therefore effective proton-electron ratio is $\sim$10 for energies $\sim$10 GeV and $\sim 10^2$ for energies $\sim$1 TeV. So qualitatively proton contamination can be estimated as proton-electron ratio divided by rejection factor. It means that for energies above 100 GeV proton contamination will be $\sim 10^{-1}$. Quantitative estimation of contamination was done by integrating of contamination from one proton over all proton spectrum:

$$\left(\frac{dN}{dE}\right)_i = \int \left(\frac{dN}{dE}\right)_p \eta_p \left(\frac{dn}{dE}\right)_p dE \qquad (1)$$

where $\left(\frac{dN}{dE}\right)_i$ – spectrum of imitations, $\left(\frac{dN}{dE}\right)_p$ – spectrum of protons, $\eta_p = \frac{1}{R}$ – efficiency of proton selection, $\left(\frac{dn}{dE}\right)_p$ – spectrum of imitations from a single proton of a given energy. Result of this integration is in agreement with estimation of imitations presented above.

Finally, for comparison of estimation of proton contamination obtained from Monte-Carlo data with estimation from flight data, a positron fraction in events selected using method described in this paper and having a good track in a magnetic spectrometer was obtained. Using positron fraction r presented in [4] a polluted positron fraction r_d was calculated:

$$r_d = \frac{\varphi_p + \alpha(\varphi_p + \varphi_e)}{\varphi_p + \varphi_e + \alpha(\varphi_p + \varphi_e)} = \frac{r}{1+\alpha} + \frac{\alpha}{1+\alpha} \qquad (2)$$

where φ_p – positron flux, φ_e – electron flux and $\frac{\alpha}{1+\alpha}$ – fraction of common positron-electron spectrum imitating by protons. Result of this calculation is presented in figure 5: empty squares are distorted ratio, small blue points are the original one, red points are obtained by the method described in this paper. So we can see that proton contamination is underestimated for energies below 50 GeV while above is in quite good agreement. This disagreement at relatively low energies could be explained by a not very high accuracy of imitation spectrum calculation because of low statisticas of protons.

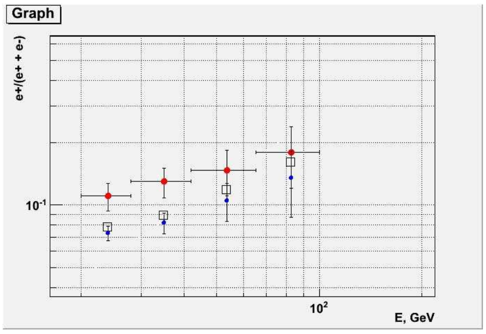

Fig. 5: Positron fraction.

But estimation from flight data shows a contamination at level of few percents as before 50 GeV and higher.

IV. CONCLUSIONS

Method described in this paper allows efficient selection of high energy electrons up to 1 TeV with acceptable proton contamination of the sample. During first general checks of the method no considerable problems were found. So this method could be used for obtaining of electron spectrum up to 1 TeV with the PAMELA instrument. Preliminary common electron-positron spectrum in energy range from 26 GeV to 1100 GeV is in agreement with the data from previous experiments as in its absolute flux and in it spectral index.

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REFERENCES

[1] P. Picozza et al., ”PAMELA - A Payload for Antimatter Matter Exploration and Light-nuclei Astrophysics ”, ApJ, 27, 296 (2007).
[2] S. Straulino, et. al, Nuclear Instruments and Methods in Physics Research A 530 (2004) 168-172.
[3] V. Bonvicini (INFN Trieste) on behalf of the PAMELA Collaboration, Calor 2008 - XIII International Conference on Calorimetry in High Energy Physics.
[4] O. Adriani et. al, Observation of an anomalous positron abundance in the cosmic radiation arXiv:0810.4995v1 [astro-ph] 28 Oct 2008.