The method of event selection for nuclei separation with the calorimeter in the PAMELA experiment

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Abstract. Here we discuss a method for a study of the heavy nuclei cosmic ray composition. The method is based on a charge separation with the PAMELA calorimeter. The work is in progress now. The ability is presented to carry out measurements up to Fe and Ni. As a result we expect to get important data about the abundance of the chemical elements in the cosmic rays.

1. Introduction
The elemental composition of the cosmic rays has been measuring during more than 50 years [1-4]. The relative distribution of elements has both similarities and differences with the composition within Solar system. Moreover it appears to show the composition at the cosmic ray sources.

Being in orbit more than 9 years the space experiment PAMELA [5] is able to carry out the study of this phenomenon as well. A good charge resolution and a wide dynamic range of the instrument detectors give the possibility to obtain the new and very important results in this subject. The obtained results will help to enlarge the understanding of the situation in the sources of the cosmic rays. In turn they can lead to an identification of the optical objects with an injection of the high-energy primary cosmic ray particles.

In this paper the selection criteria are discussed as well as the possibility to study the nuclei energy determinations in the PAMELA experiment.

2. The PAMELA experiment
The PAMELA apparatus [5] was has been working in orbit just 10th year. It is installed on board of the Resurs DK1 satellite and is accumulating the scientific information up to now. The satellite orbit was elliptical and polar with an inclination of 70.4°. The main objective of the PAMELA experiment is to study the composition and energy spectra of cosmic rays over a wide range of energies. The PAMELA apparatus (fig. 1) consists of a number of special detectors: a magnetic spectrometer with position sensitive silicon detectors, a time-of-flight (TOF) system with three double planes of scintillators, an anticoincidence system, a neutron detector, a bottom shower scintillator detector S4, and a multilayer calorimeter. The geometrical factor for high energy particles (>1 GeV) passing through the sensitive volume of the magnetic spectrometer is 21.6 cm²sr. Its angular aperture is of 19° × 16°.
One of the features of the apparatus is the possibility to extend its angular aperture using as a main detector the position sensitive calorimeter. This makes it possible to increase statistics by two orders. The PAMELA calorimeter consists of 22 tungsten plates with thickness 2.6 mm interleaved by silicon strip detector planes 380 micron thick. Strips of adjacent planes are perpendicular. The strip pitch is 2.2 mm. The detailed description can be found in [6]. Each registered particle gives the information consisting of a set of detector responses formed an event written into instrument memory. As the calorimeter is a position sensitive one the set of event data consist of the amplitudes and coordinates of strips along the particle track. This gives the possibility to restore the particle parameters and to identify a particle type. In this work we discuss the possibility of studying the nuclei with Z more than 6 in the cosmic rays.

3. The track selection
First of all the events were studied for the reconstructed particle tracks in the calorimeter. The events were selected within a wide aperture. This aperture being larger by 100 times than the magnetic spectrometer one is defined by the calorimeter and S4 triggers [7]. This provides a high level of statistics which is especially important from point of view of a heavy nuclei search. The basis of our approach is a track selection procedure for primary particles interacted inside the calorimeter. This procedure (precisely described elsewhere see [8]) was developed to obtain the axis of shower of secondary particles initiated by primary particle within the calorimeter. With some modernizations it was used for a selection of events without any hadron interactions inside the calorimeter or any part of the PAMELA instrument itself before penetration into the calorimeter. The selected events include inter alia the particles which were stopped inside the calorimeter or crossed only several calorimeter planes (see fig. 2). The comparison of events before and after this selection demonstrated the high level of efficiency of this selection. For a primordial analysis only a single track events without any interactions inside the calorimeter were considered.
Figure 2. The experimental events. These kinds of events were selected among others for future analysis.

4. The nuclei separation
The next step was to extract the nuclei among the events obtained in the previous stage. The nuclei separation was based on the ionization losses (dE/dx) measurements of the particle along its track in the calorimeter planes. The search was expected to be done for relativistic nuclei with the charge up to heavy elements like Fe and Ni. The selection of nuclei in our method starts from the charge of carbon (Z = 6). This corresponds to a lower threshold for total energy released cut equals to 1500 mip. The (dE/dx) is measured in terms of mip as well, where mip is an energy release of minimum ionization particle. In fig. 3 the visualized events with Ne (Z = 10) Si (Z = 14) and Fe (Z = 26) nuclei are demonstrated. They were selected in accordance with such a relatively simple parameter as an average energy released per single calorimeter plane ∼ 100 mip, 200 mip and 700 mip correspondingly. These elements are ones of the most abundant in the cosmic rays [9].

Today our work is in progress and the method is developing and improving. The selection criteria are under the testing. Truncated mean method will be used to obtain the mean value of energy release while the highest values of ionization are not taken into account. This increase the charge resolution as the "tail" values of Landau curve of ionization losses [10] is not used. The other means of data treatment, such as considering the distribution of released energy between strips assembling clusters near the track position in the plane or taking into account the events with interactions, will be consider as well. All these ways should definitely increase statistics of identified nuclei.

5. The future analysis and conclusion
Unfortunately this approach does not allow measuring of nuclei energy because magnetic spectrometer cannot be used. Described separation of particles according their charge with the calorimeter allows only constructing a charge distribution of registered nuclei to study
Figure 3. The selected nuclei tracks - Ne, Si, Fe in the experimental data.

...an elemental composition of cosmic rays. Nevertheless as the measurements are carrying out in magnetosphere the Earth magnetic field might be used as rigidity separator. The energy thresholds can be installed by taking into account the cut-off rigidity of different areas of the satellite position. By such a way the heavy nuclei charge distribution can be expected to obtain depending on threshold energies.

So the study cosmic ray elemental composition is possible in frame of PAMELA experiment. The events of high Z value nuclei (up to Ni) were found in data set of experiment. The method of nuclei selection is under development and shows a perspective. The energy dependence of Z-distribution can be obtained from cut-off rigidities of measurement positions.

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