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# The NUCLEON Instrument Prototype Beam Tests and Detailed Simulation

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The results of beam tests of the NUCLEON device prototypes and simulation of the experiment are discussed. Satisfactory agreement of the experimental and simulation data is shown. The trigger criteria, trajectory reconstruction, energy and charge measurements are considered.

## 1. Introduction

The main aim of this work is to investigate opportunities for cosmic ray energy spectra reconstruction by the NUCLEON satellite experiment [1-5]. The design of the apparatus [5] was modified according to the new real satellite parameters, so the new runs of simulations are presented here. We analyze the accuracy of the energy spectra reconstruction, charge measurements and trigger criteria for the possibility of background rejection. The beam tests [6] were performed to investigate energy and charge parameters of the new device. In this paper we present some results of beam tests in comparison with the Monte-Carlo simulation data.

## 2. Energy spectra reconstruction

The structure of spectrometer NUCLEON is described in [5]. The trigger system includes 6 layers of scintillation strip detectors. The Monte-Carlo simulation was performed by GEANT 3.21 program. Nuclear interactions were generated by different models. Protons and iron nuclei were simulated in energy region $10^9$-$10^{15}$ eV per particle. We simulated fluxes of protons and iron nuclei with isotropic arrival distribution from an upper hemisphere. To reject background events (mostly formed by side events and low energy particles) we work out the multilevel trigger criteria including the simple on-board selection by scintillation signal thresholds and off-line analysis of spatial distribution of ionization. As it was found, the simple on-board selection permits to reject the main part of background events (>99%), low energy particles in general. This allows to decrease the information volume transmitted to the Earth significantly. Moreover, the trigger criteria are energy independent at high energies.

Further, selected by trigger criteria events were used to reconstruct energy spectra. Our method of energy reconstruction is based on the measuring spatial density of secondary particles below the tungsten converter [1-3]. The calculated accuracy of energy determination in one event is equal to 0.7÷0.8 for different components. Examples of simulated and reconstructed energy spectra for protons and Fe-nuclei are shown in Figure1. As it can be seen the applied method reconstructs the energy spectra satisfactory, while the accuracy in individual event is not so good. This is well known effect for cosmic ray physics: the accuracy of the slope measurements for very steep power energy spectra depends on the statistics much more than on individual event accuracy [7]. Therefore we put main efforts to increase the geometric factor of the

NUCLEON device rather than to improve the accuracy in an individual event. The 5-year exposition of the NUCLEON device can provide Δγ accuracy about 0.1 at energies more than 50 TeV for protons and iron nuclei and more than 4 TeV for boron nuclei.

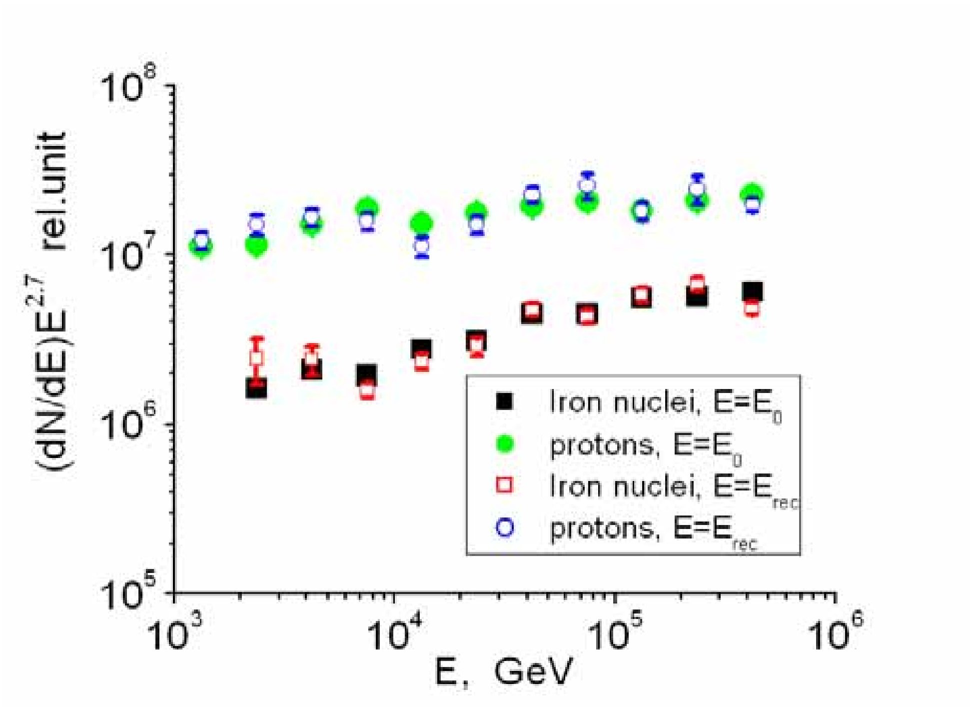


**Figure 1.** The NUCLEON device simulation results. Energy spectra reconstruction.

## 3. Energy reconstruction in accelerator tests

The experiments in CERN were performed to test our simulation results. Different variants of the NUCLEON device construction were exposed with the pion beams of energy 200 and 350 GeV in 2004. The simulations of beam tests were performed for every variant too. Detector responses in all considered variants of tests are reproduced well enough by Monte-Carlo simulations with GEANT3.21 complex. The results of this analysis confirmed our suggestion about the opportunity of the NUCLEON device to measure energy of particle by the KLEM method. Examples of reconstructed energy distributions are shown in Figure2 for experimental and simulated events for negative pions with energy 350 GeV. The mean values of reconstructed energies and RMS are presented in table 1. Thus our experimental and simulation data are in an agreement.

**Table 1**. Parameters of Energy Measurements by Beam Test

| | Mean Reconstructed Energy, *GeV* | RMS σ |
|---|---|---|
| Experiment | 334 | 0.79 |
| Simulation | 350 | 0.78 |

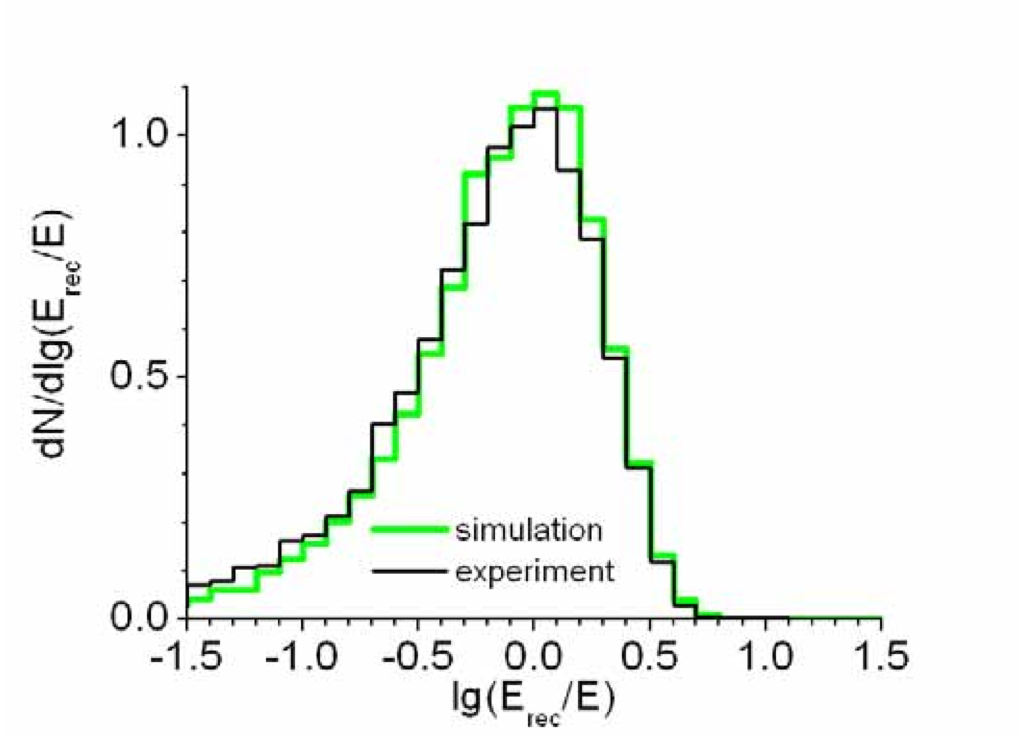


**Figure 2.** Reconstructed energy distributions ($\pi^-$, 350 GeV, 1.05 cm of tungsten, logarithmic scale).

## 4. Charge detector test

The prototype of charge detector was tested by ion CERN beam in 2003 [6]. Different nuclei are produced in processes of indium beam fragmentation at interaction in beryllium target and then are sorted by magnetic rigidity. This scheme of the experiment allowed to test our apparatus in wide charge area. The charge detector consists of 4 silicon detectors layers. The special statistical algorithm was applied for the charge determination using all 4 layers. The layer signals are arranged in ascending order $I_1 \le I_2 \le I_3 \le I_4$. The charge can be determined by the signal $I_2$. This method decreases charge measurement errors caused by ionization fluctuations, nuclear interactions in matter of the detector and back scattered particles, produced in the tungsten converter. As well known just the back scattered particles drastically make worse the charge resolution at small value of Z. Examples of obtained charge distributions are presented in Figure3 in comparison with simulated data. There is a satisfactory agreement of experimental and simulation results. Small difference for light nuclei can be explained by simultaneous registration of a few particles. The charge detector resolution allows to separate different elements. Thus we can measure fluxes of different nuclei.

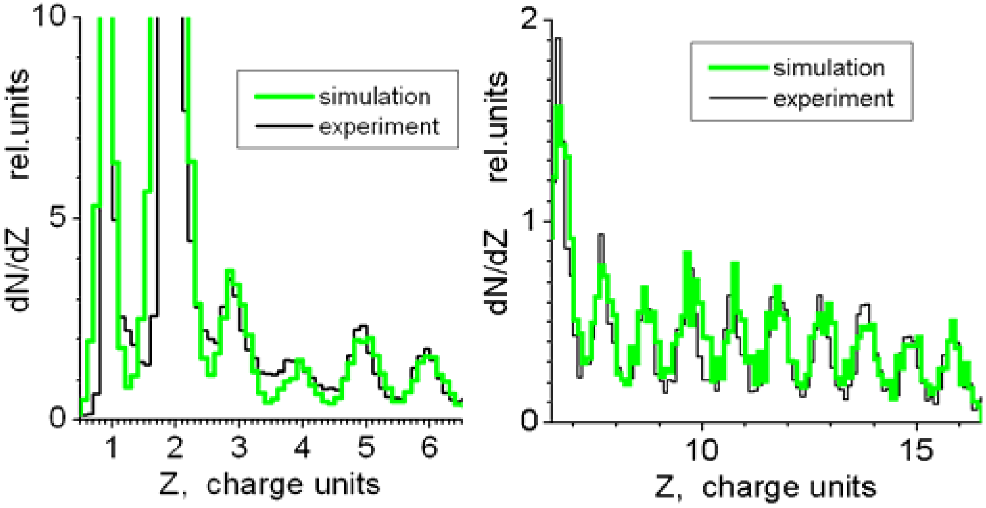


**Figure 3.** Charge distributions for heavy ion beam test in 2003 at CERN SPS.

## 5. Conclusions

The performed simulation has shown an opportunity of cosmic ray energy spectra reconstruction by the NUCLEON satellite experiment. The simple trigger criteria permit to reject the main part of background events. Charge detector resolution allows to separate different nuclei. The large experimental material obtained by beam tests confirms simulation data about charge and energy characteristics of the NUCLEON device.

## 6. Acknowledgements

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