PROCEEDINGS OF SCIENCE

The NUCLEON Space Experiment present status

D.Podorozhny[*1], E.Atkin[2], V.Bulatov[3], V.Dorokhov[3], N.Gorbunov[4], S.Filippov[3], V.Grebenyuk[4], D.Karmanov[1], I.Kovalev[1], I.Kudryashov[1], M.Merkin[1], A.Pakhomov[1], A.Panov[1], D.Polkov[3], S.Porokhovoy[4], V.Shumikhin[2], L.Sveshnikova[1], A.Tkachenko[4,5], L.Tkachev[4], M.Torochkov[1], A.Turundaevskiy[1], O.Vasiliev[1], A.Voronin[1]

[1]*Skobeltsyn Institute of Nuclear Physics, Moscow State University, Moscow, 119991, Russia*
[2]*National Research Nuclear University "MEPhI", Moscow, 115409, Russia*
[3]*SDB Automatika, Ekaterinburg, 620075, Russia*
[4]*Joint Institute for Nuclear Research, Dubna, 141980, Russia*
[5]*Bogolyubov Institute for Theoretical Physics, Kiev, Ukraine*
E-mail: `dmp@eas.sinp.msu.ru`

The NUCLEON satellite experiment is designed to investigate directly, above the atmosphere, the energy spectra of cosmic-ray nuclei and the chemical composition (Z=1-30) at energy range 100 GeV - 1000 TeV. The effective geometric factor is more than 0.2 m^2sr for nuclei and 0.06 m^2sr for electrons. The satellite was launched in 26 December 2014. The planned exposition time is more than 5 years.

The 34th International Cosmic Ray Conference
30 July- 6 August, 2015
The Hague, The Netherlands

[*]Speaker

1.Introduction

The NUCLEON satellite experiment is designed to investigate the energy spectra of cosmic ray nuclei and the chemical composition from 100 GeV up to 1000 TeV (closely to the "knee"). The additional aim is the cosmic-ray electron spectrum measurement (from approximately 100 GeV to 3 TeV). The "knee" energy range 10^{14} - 10^{16} eV is a crucial region for the understanding of the cosmic-ray acceleration and propagation in the interstellar medium. It is important to obtain more data with elemental resolution. The "knee" area is interesting for astrophysics. New experiments over a wide charge and energy range are needed. The NUCLEON satellite was launched in 26 December 2014. This mission is aimed at clarifying the essential details of cosmic-ray origin in this energy interval: number and types of sources, identification of actual nearby sources, the investigation of the mechanisms responsible for the knee. Specific features of the NUCLEON instrument are a relatively small thickness and a small weight. A new method of energy determination by the silicon tracker (KLEM [1]) was developed for this case.

2.The NUCLEON design

The NUCLEON apparatus [1] was designed and produced by a collaboration of SINP MSU (main investigator), JINR (Dubna) and some other Russian scientific and industrial centers. It is placed now on board of the RESURS-P №2 satellite. The spacecraft orbit is a Sun-synchronous one with inclination 97.276^o and a middle altitude of 475 km. The effective geometric factor is more than 0.2 m^2sr for the KLEM subsystem and near 0.06 m^2sr together with the calorimeter. The surface area of the device is equal to 0.25 m^2. The NUCLEON device general configuration is presented in fig.1

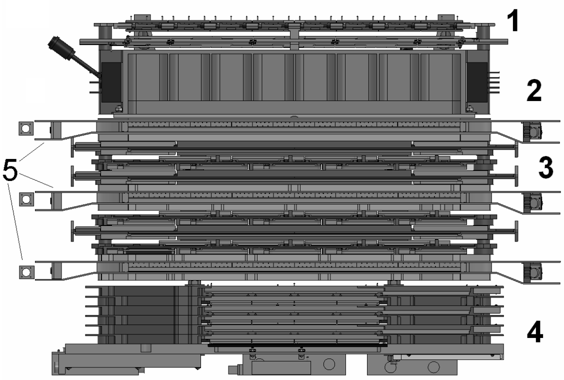

Figure 1: The NUCLEON device general configuration

The NUCLEON apparatus includes the charge measurement system consisting of the 4 pad silicon detectors layers (1), the KLEM energy measurement system of the carbon target (2) and the silicon microstrip detectors divided by thin tungsten layers (3), the trigger system of the 6 scintillator layers (5) and the calorimeter (4). Silicon detectors consist of unified ladders.

The set of data obtained by all detectors for an event can be presented in the form of a "portrait" of the event. One example of an event portrait is shown at fig.2.

Four charge detector layers are presented in the left top corner of the figure. Circles correspond to worked pads. The side projections of events are presented for silicon and scintillator detectors. These data are used for analysis.

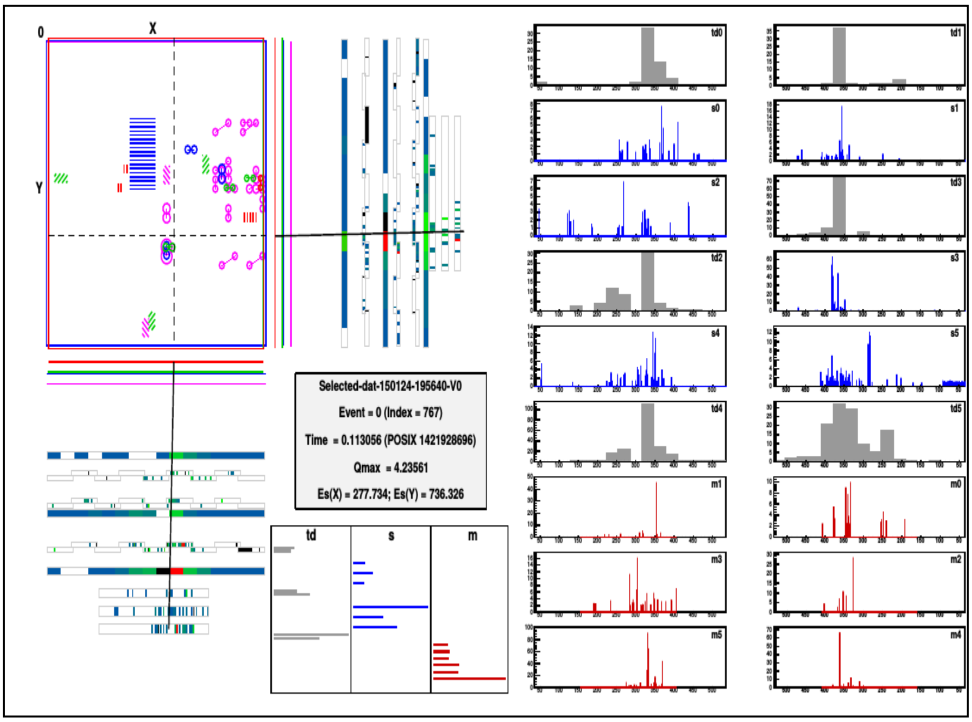

Figure 2: The image of the event. The boron nucleus initialized the shower

3.The charge measurements

The charge measurement system is designed for precision measurement of the primary particle charge and consists of four thin detector layers of 1.5×1.5 cm silicon pads. Each readout channel is used for the two pads to decrease number of channels. Signals of connected pairs of pads from different parts of the detector are summed. Probability of simultaneous registration of a particles in each member of a pair is small and may be accounted for by a simulation of the apparatus. Charge measurement system readout chips CR-1 have a dynamic range ~1000 mip. The charge measurement system should provide resolution better than the 0.3 charge unit according to results of simulation and beam tests.

The signals from microstrip detectors are used to reconstruct a shower axis. Then charge detector pads near the axis are selected. Information on the incident particle charge is measured by each of four silicon layer separately and it guarantees a higher accuracy of measurement than achieved by a single layer. Various algorithms of particle charge reconstruction. The calibration curves were obtained for all channels.

The charge measurements of the four detectors were matched using the rank statistics method [2]. For each recorded event four charges were measured by the four detectors and arranged in ascending order (regardless of the detector to which a particular charge corresponded). The next step was to determine the charge that is second in magnitude, and this value was used as the estimate for the charge. It should be noted that the rank statistics method provides better results than simple averaging of values, since fluctuations of the ionisation losses have a sharply asymmetrical form, as opposed to the standard distribution of errors. This method decreases errors caused by nuclear spallation and secondary particles generation in the detector.

The charge measurements were tested at ion beams [1, 2]. In the Charge Measurement System (CMS) the peaks from different nuclei up to Z=30 with reasonable separation were collected. The results of measurements are shown on fig.3 (solid line) in comparison with a multi-gaussian fit (dashed line). Also the channel gain in electronics of the charge measurement system is not perfectly linear, the real signal from the heavy nuclei (Z>25) is higher than it should be from the standard dependence of the signal on the square of nuclear charge. The non-linearity of the CMS was corrected.

The charge distribution obtained by the first stage of the NUCLEON satellite experiment is presented in fig.4. The preliminary analysis provides charge accuracy near 0.3. It is possible to improve resolution of measurements by means of further developing of the algorithms related the shower axis reconstruction, active silicon pads selection and others..

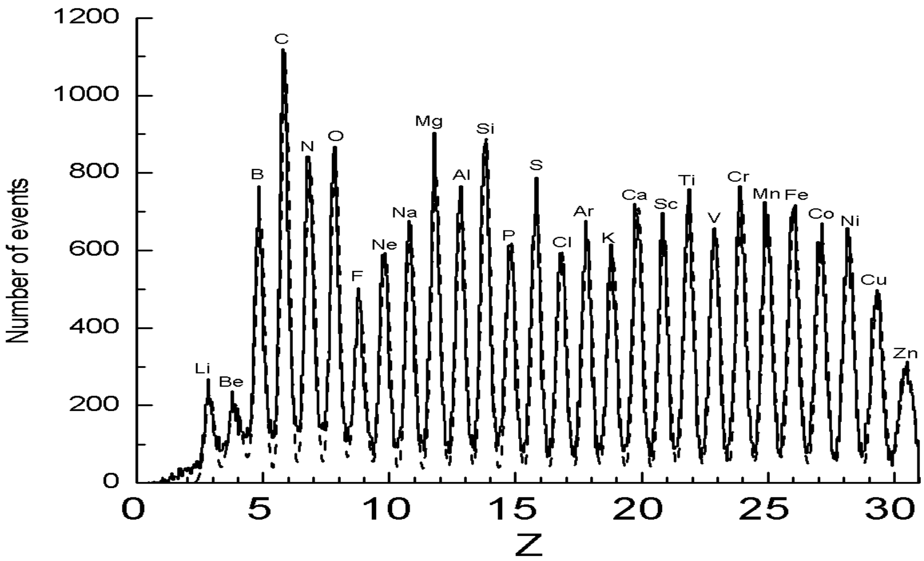

Figure 3: The charge distribution obtained by the beam test

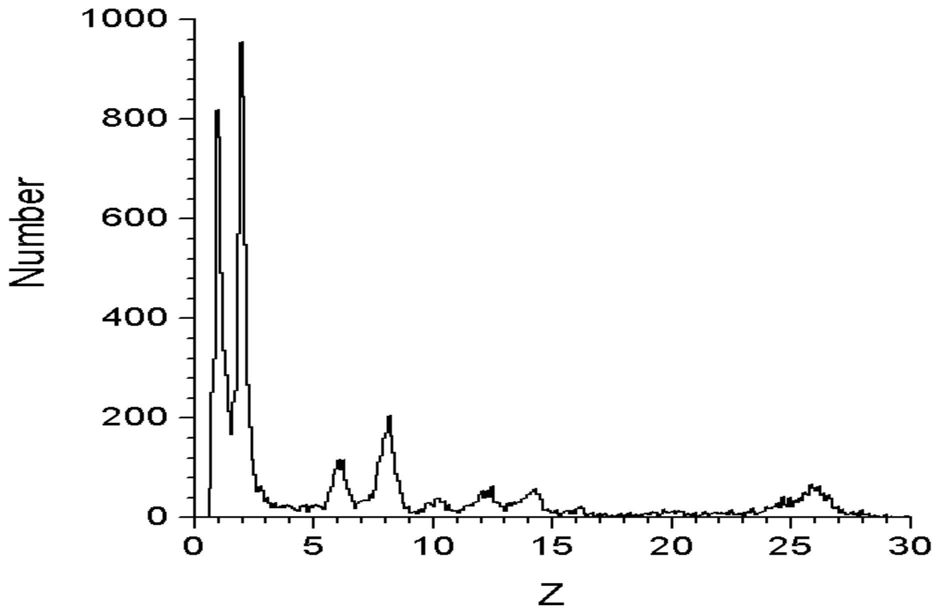

Figure 4: The preliminary charge distribution obtained by the space experiment

4. The energy measurement system and the available primary particles energy range with NUCLEON statistics

The energy measurement system is based on KLEM technique [1]. Tungsten layers of the tracker significantly increases the number of secondary particles and therefore improves the accuracy of a primary particle energy determination. The pitch of microstrips is equal to 484 μm. Every strip is connected to its own readout channel. The pairwise-perpendicular strip orientation makes it possible to perform analysis for each (X and Y) direction independently and improve the primary particle energy resolution.

The particle energy also can be reconstructed by traditional calorimeter technique (Micro Ionization Calorimeter – MIC) for showers traversed not only the tracker but the ionization calorimeter too. The deposited energy was determined by summation of all signals in the calorimeter microstrip detectors. Cascade curves were reconstructed by means of interpolation. The simulation results of both methods – KLEM and calorimetric – may used to improve the accuracy of measurement of the primary particle energy and to test new KLEM technique versus the traditional calorimetric method.

The distribution of ratio E_{KLEM}/E_{MIC} for primary protons is presented in fig.5. The energy was determined by two methods simultaneously for each event (E_{KLEM} and E_{MIC}). The Pearson product-moment correlation coefficient for E_{KLEM} and E_{MIC} is equal to 0.82. Energy values determined by two methods are close. The middle ratio E_{KLEM}/E_{MIC} is equal to 0.87. It is a systematic error of energy measurements and it is significantly less than statistical errors.

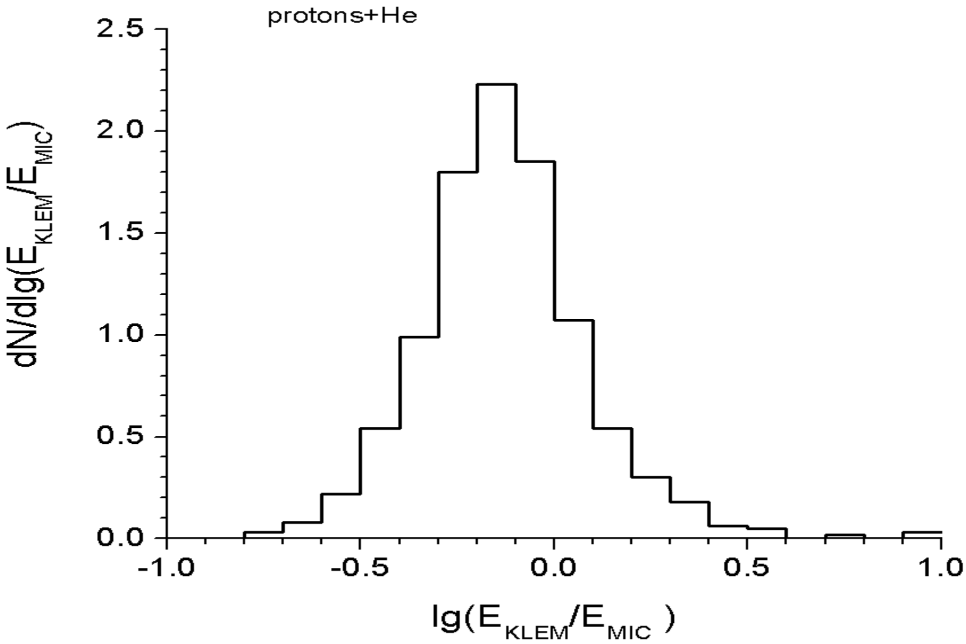

Figure 5: The distribution of ratio E_{KLEM}/E_{MIC}

Starting at February 2015 the NUCLEON observatory is in continuous operation and collection of statistics. We do not show detailed measured energy spectra of various particles in this paper since the analysis now is in the very preliminary stage. But we show some approximate data indicating the rate of the collection of statistics under different energies of primary cosmic ray particles.

Table 1: The five months collected statistics for various energies of particles in the all-particle flux.

E deposit (MIC), MIPs	Estimated *E* primary, TeV	Number of particles
10^4	1	30500
10^5	10	1400
10^6	100	33
10^7	1000	3

The number of events with different energy deposition in the calorimeter detected by the NUCLEON observatory during the first five months of operation are shown in Tab. 1. This events were registrated within the calorimeter aperture and related staistics correspond to the geometric factor 0.06 m^2sr of the calorimeter. The energy depositions in the calorimeter in the units of MIPs are shown in the first column in Tab. 1. To recalculate the energy deposit of the calorimeter to the energy of primary particles in TeV the energy deposit was multiplied by the factor 0.0001 obtained by simulation (the second column). This estimation still is very approximate and preliminary and the error of the scale of 1.5 may be expected. The numbers of particles with the energy above the energy thresholds indicated in the first and second columns, are shown in the last column. It is seen that there are already three particles with energies above 1 PeV (it is close to the expected value). One may conclude that about 30-40 particles above 1 PeV within the calorimeter aperture may be expected for five years NUCLEON statistics. KLEM aperture is more than three times higher than the calorimeter aperture, therefore it may be expected about 100 events above 1 PeV in the KLEM aperture during 5 years collection of statistics. These values mean that the spectra of particle may be measured with reasonable statistical significance up to energies 1 PeV per particle in the NUCLEON experiment during five years of operation.

5.Summary

The NUCLEON apparatus was designed and tested. The RESURS-P satellite with the NUCLEON spectrometer onboard was launched 26 December 2014. The experiment was successfully started and data collection now is on. The expected performance is confirmed by the simulation, beam tests and first space experiment results. All the scientific objectives are achievable. Statistically significant measurements of the energy spectra of nuclei up to energies about 1 PeV per particle are expected. We obtain and analyze the first data.

References

[1] E.Atkin, V.Bulatov, V.Dorokhov et al., *The NUCLEON space experiment for direct high energy cosmic rays investigation in TeV–PeV energy range*, Nucl. Instr. and Meth. in Phys. Research **A770** (2015) 189

[2] A.Voronin, V.Grebenyuk, D.Karmanov et al., *Testing a Prototype of the Charge-Measuring System for the NUCLEON Setup,* Instruments and Experimental Techniques. **50**, (2007) 187