The NUCLEON Space Experiment

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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 m2sr for nuclei and 0.06 m2sr for electrons. The planned exposition time is more than 5 years.

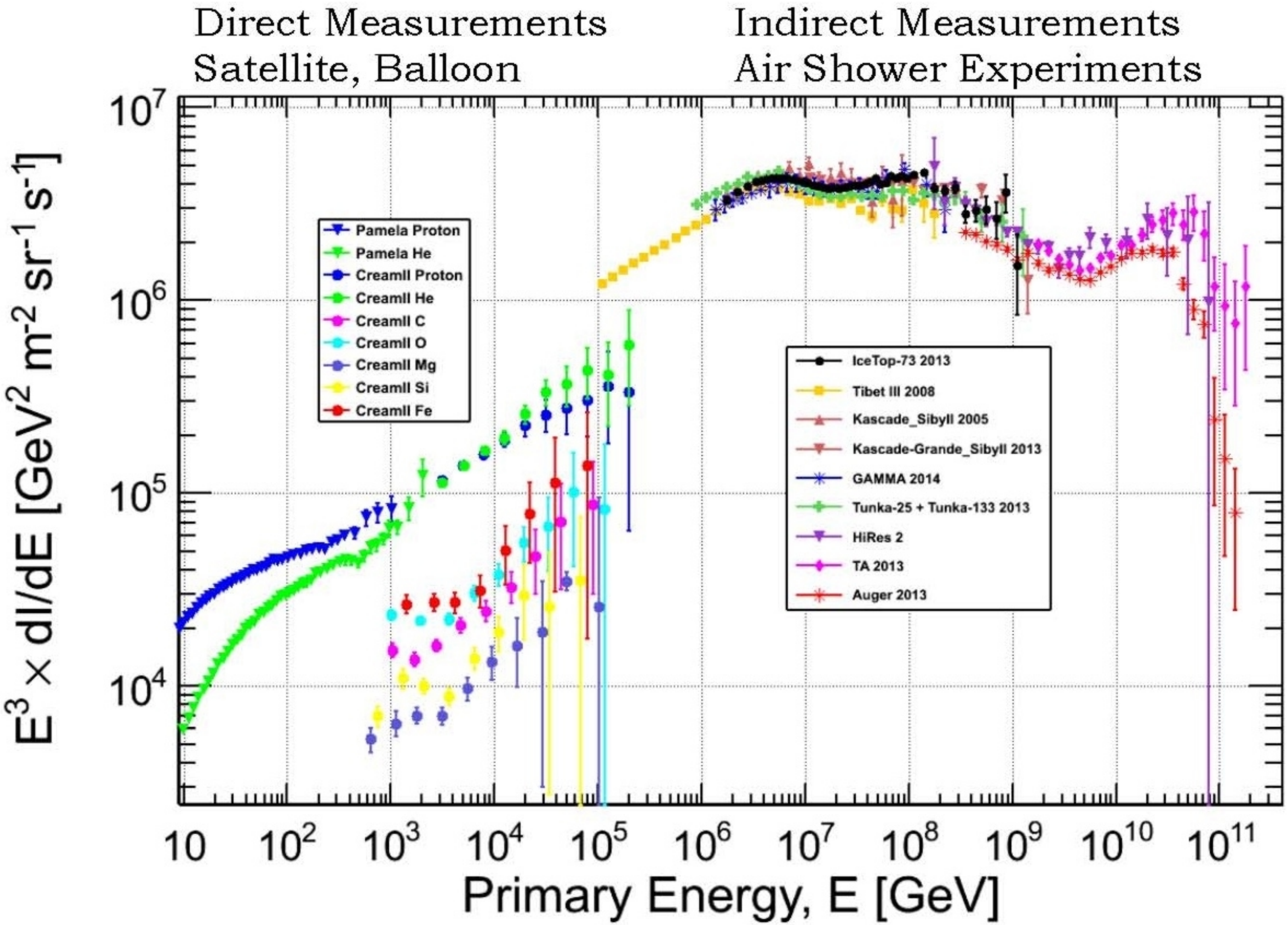
The satellite was launched in 26 December 2014.

The aims of the experiment

- The main aim is to measure chemical composition and energy spectra at wide energy range 100 GeV – 1 PeV (before the "knee") including the secondary to primary nuclei ratio.
- The additional aim is electron energy spectrum measurement (100 GeV – 3 TeV)

Other experiments with close aims:

PAMELA, AMS02, FermiLAT, CALET



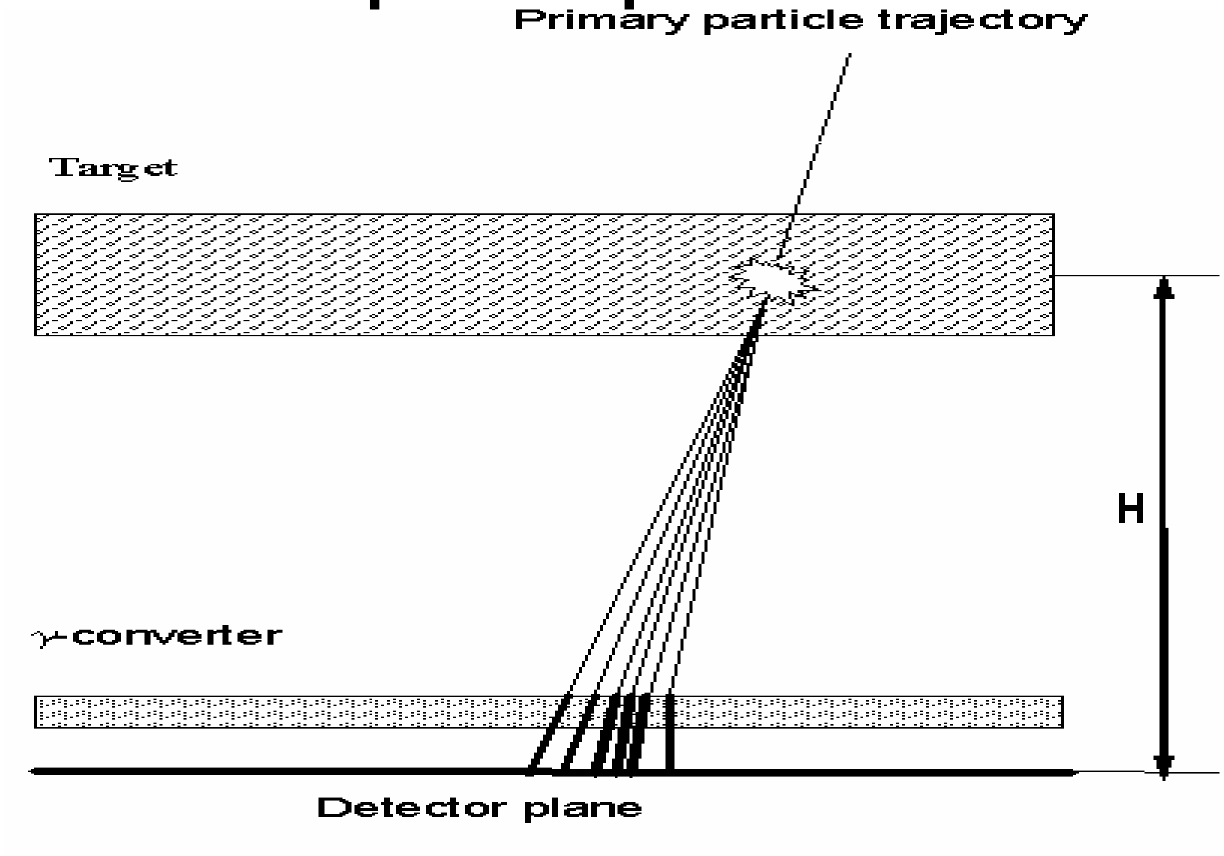
- Cosmic rays flux (particles $m^{-2} sr^{-1} year^{-1}$)

(>E)	10^{14}	10^{15}
	2100	46

Energy measurements

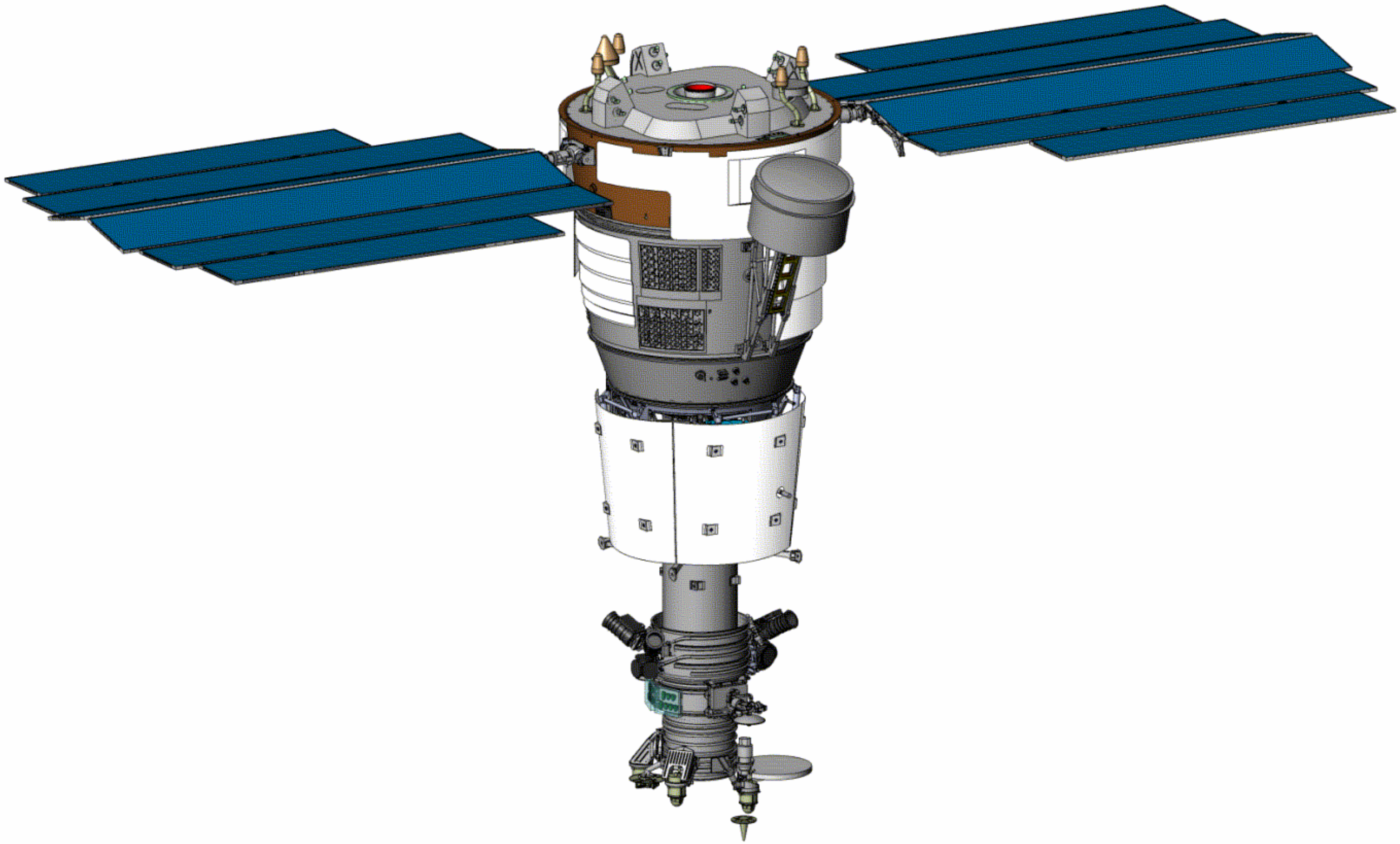
- Now the most universal energy measurements technique is ionisation calorimeter. This method is reliable but a calorimeter needs a heavy absorber to register high energy showers. Weight restrictions limit the application of ionisation calorimeters for cosmic-ray investigation on board of satellites at energies >100 TeV.
- A new energy measurement method was proposed. The primary energy is reconstructed by registration of spatial density of the secondary particles. The particles are generated by the first hadronic inelastic interaction in a carbon target. Then additional particles are produced in thin tungsten converter by electromagnetic and hadronic interactions. Thus it is possible to design relatively light cosmic rays’ detectors with a large geometric factor.

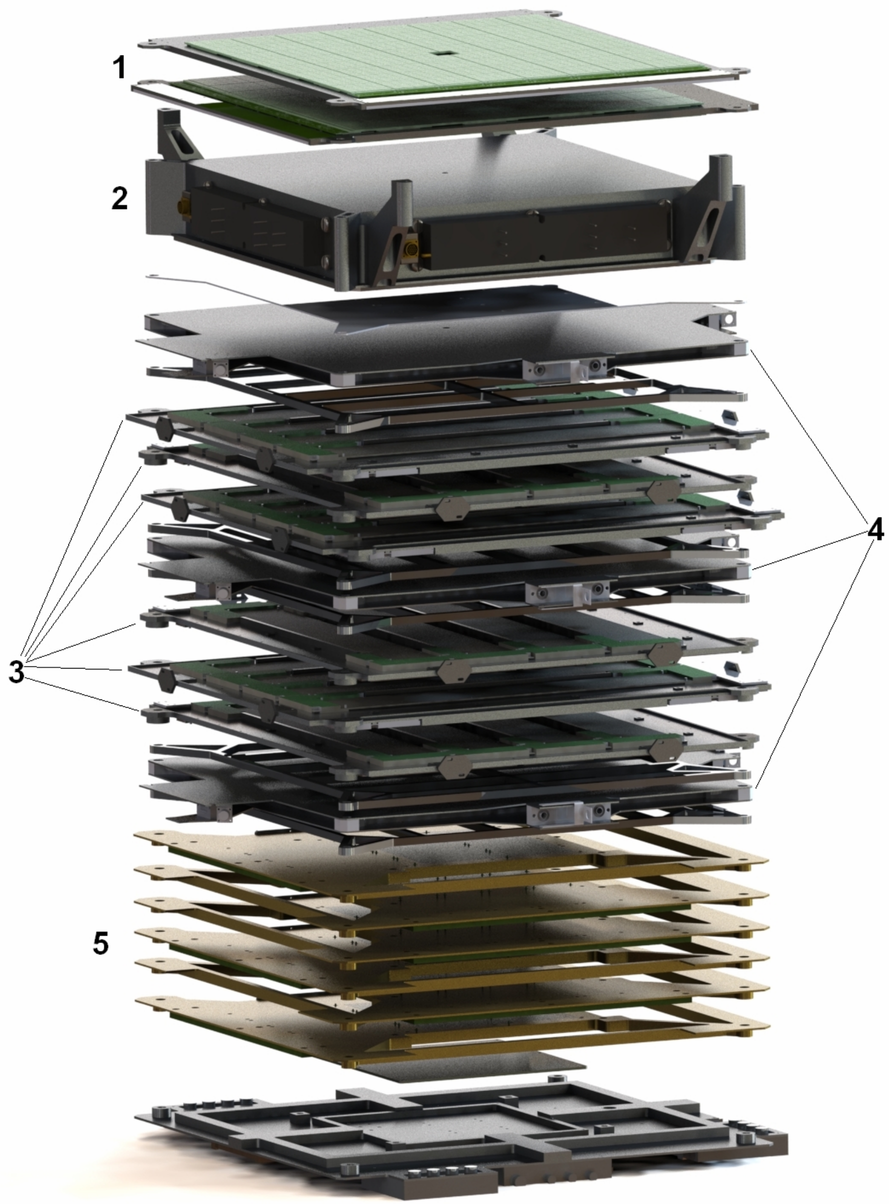
The principal scheme



The RMS is equal to ~70%. The method is described in
Adams J., Bashindzhagyan G., Chilingaryan A., Drury L., Egorov N., Golubkov S., Korotkova N., Panasyuk M., Podorozhnyi D., Procquereur J., Roganova T., Saavedra O., Sidorov A., Simon M., Sveshnikova L., Turundaevsky A., Yashin I.
Particle Energy Determination Device for the International Space Station Using a New Approach to Cosmic Ray Spectral Measurements (TUS-M Mission)
AIP Conference Proceedings. 2000. A14-165. V.504. P.175-180

The NUCLEON device on the RESURS-P satellite



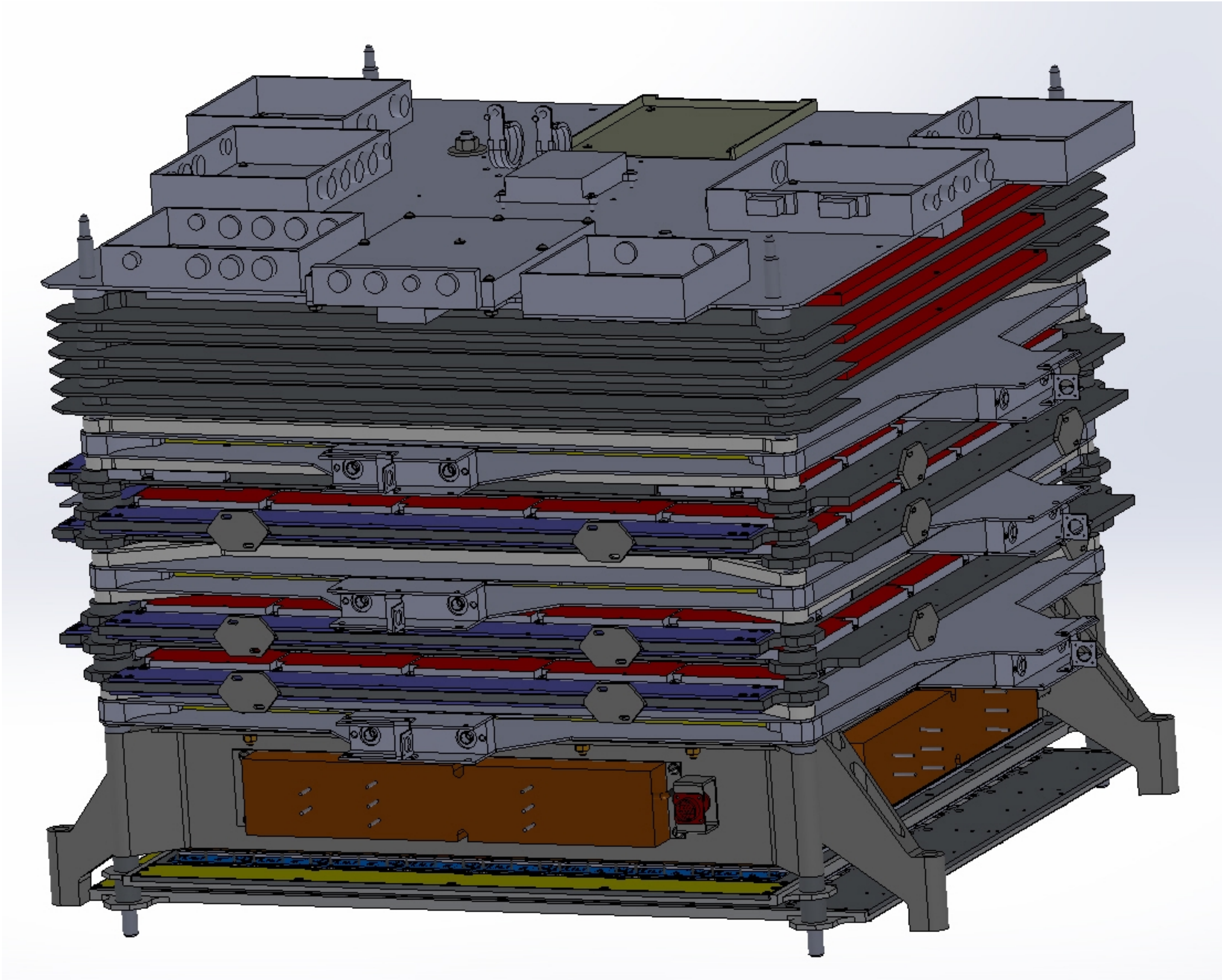


The NUCLEON apparatus includes the charge measurement system consisting of the 4 pad silicon detectors layers (1), the energy measurement system consisting of the carbon target (2) and the silicon microstrip detectors divided by thin tungsten layers (3), the trigger system consisting of the 6 scintillator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

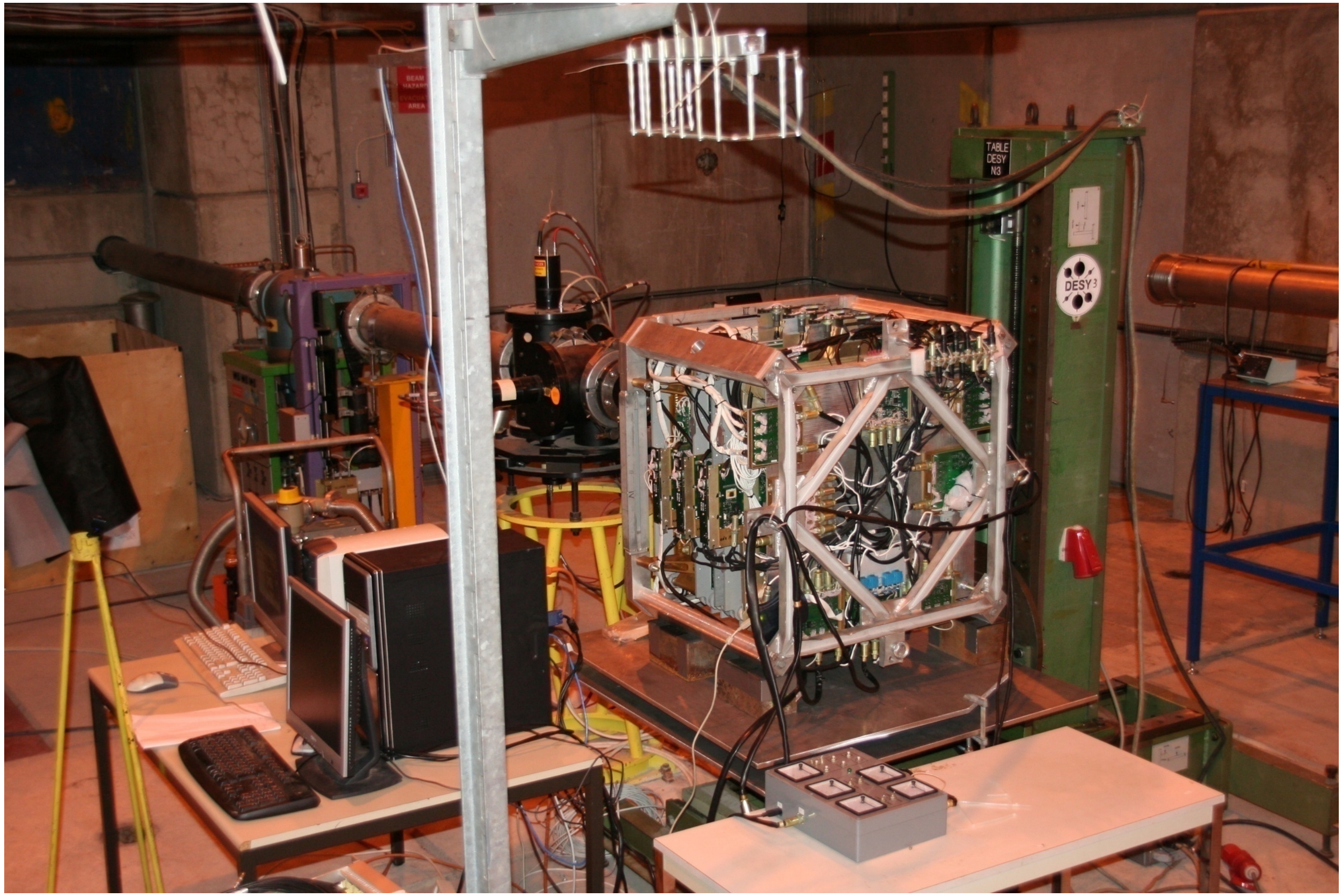
The weight restrictions allow to include the little calorimeter. Its transversal size was limited to 250x250 mm and a weight of ~26 kg. It is applied for energy calibration and for electromagnetic component registration.

15.2 radiation lengths

The NUCLEON device weight is equal to ~300 kg, power consumption is equal to 150 W. The effective geometric factor is more than 0.2 m2sr for nuclei and 0.06 m2sr for electrons. The planned exposition time is more than 5 years. Energy resolution ~70% for nuclei and ~8% for electrons, charge resolution is ~0.2-0.3 charge unit.



The flight NUCLEON model at the H8 SPS beam test at 2012



Beam tests results are published

A. G. Voronin, V. M. Grebenyuk, D. E. Karmanov, N. A. Korotkova, Z. V. Krumshtein, M. M. Merkin, A. Yu. Pakhomov, D. M. Podorozhnyi, A. B. Sadovskii, L. G. Sveshnikova, L. G. Tkachev, A. N. Turundaevskii

Testing the Prototype of the NUCLEON Setup on the Pion Beam of the SPS Accelerator (CERN) **Instruments and Experimental Techniques, 2007. V. 50, N. 2, p.176**

A. G. Voronin, V. M. Grebenyuk, D. E. Karmanov, N. A. Korotkova, Z. V. Krumshtein, M. M. Merkin, A. Yu. Pakhomov, D. M. Podorozhnyi, A. B. Sadovskii, L. G. Sveshnikova, L. G. Tkachev, A. N. Turundaevskii

Testing a Prototype of the Charge-Measuring System for the NUCLEON Setup **Instruments and Experimental Techniques, 2007. V. 50, N. 2, p.187**

V.L. Bulatov, A.V. Vlasov, N.V. Gorbunov, V.M. Grebenyuk, D.E. Karmanov, A.Yu. Pakhomov, D.M. Podorozhnyi, D.A. Polkov, L.G. Tkachev, A.V. Tkachenko, S.P. Tarabrin, A.N. Turundaevskii, S.B. Filippov

Testing the Engineering Sample of the NUCLEON Setup on a Pion Beam

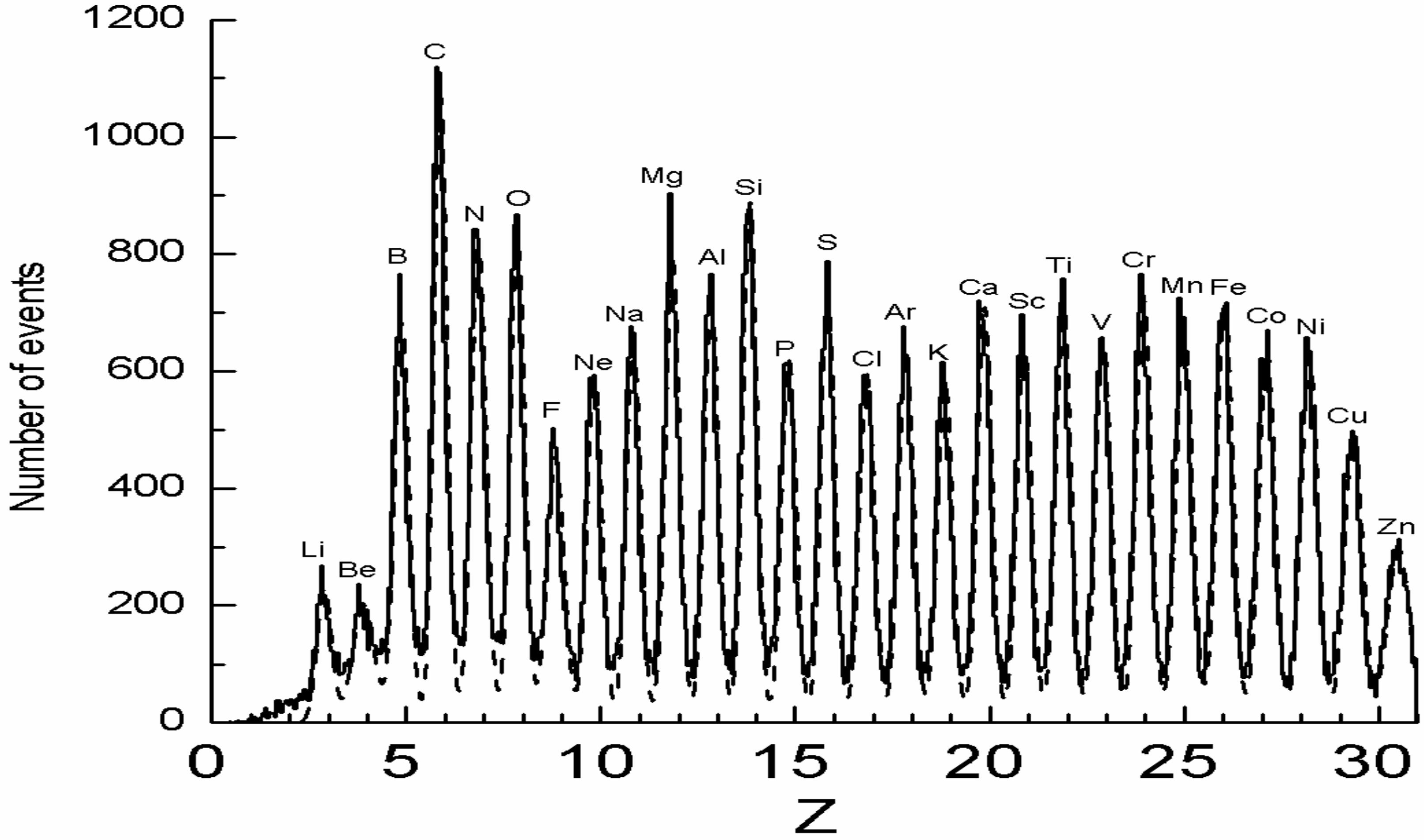
Instruments and Experimental Techniques, 2010, Vol. 53, N1, p. 29

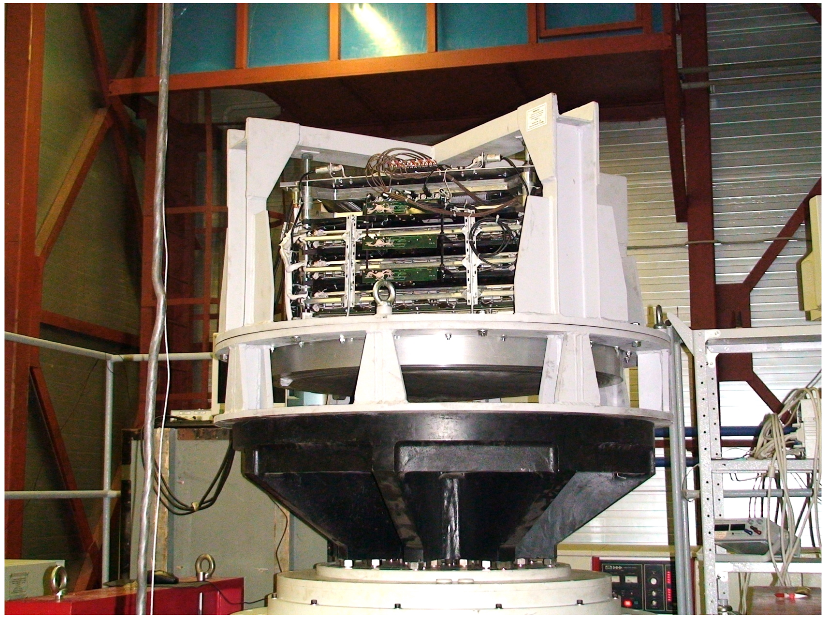
E.Atkin, V.Bulatov, V.Dorokhov, N.Gorbunov, S.Filippov, V.Grebenyuk, D.Karmanov, I.Kovalev, I.Kudryashov, M.Merkin, A.Pakhomov, D.Podorozhny, D.Polkov, S.Porokhovoy, V.Shumikhin, L.Sveshnikova, A.Tkachenko, L.Tkachev, A.Turundaevskiy, O.Vasiliev, A.Voronin

The NUCLEON Space Experiment for Direct High Energy Cosmic Rays Investigation in TeV-PeV energy range

Nuclear Instruments and Methods in Physics Research A770 (2015) p.189

Beam test charge distribution (solid line) in comparison with the multi-Gaussian approximation (dashed line). Charge error ~0.2



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Summary

The NUCLEON device was designed and tested. The expected performance is confirmed by simulation and beam test results. All scientific objectives are achievable. The RESURS-P satellite was launched 26 December 2014. We obtain the first data.

The launch of the rocket Sojuz-2.1b with RESURS-P №2 satellite at 26.12.2014

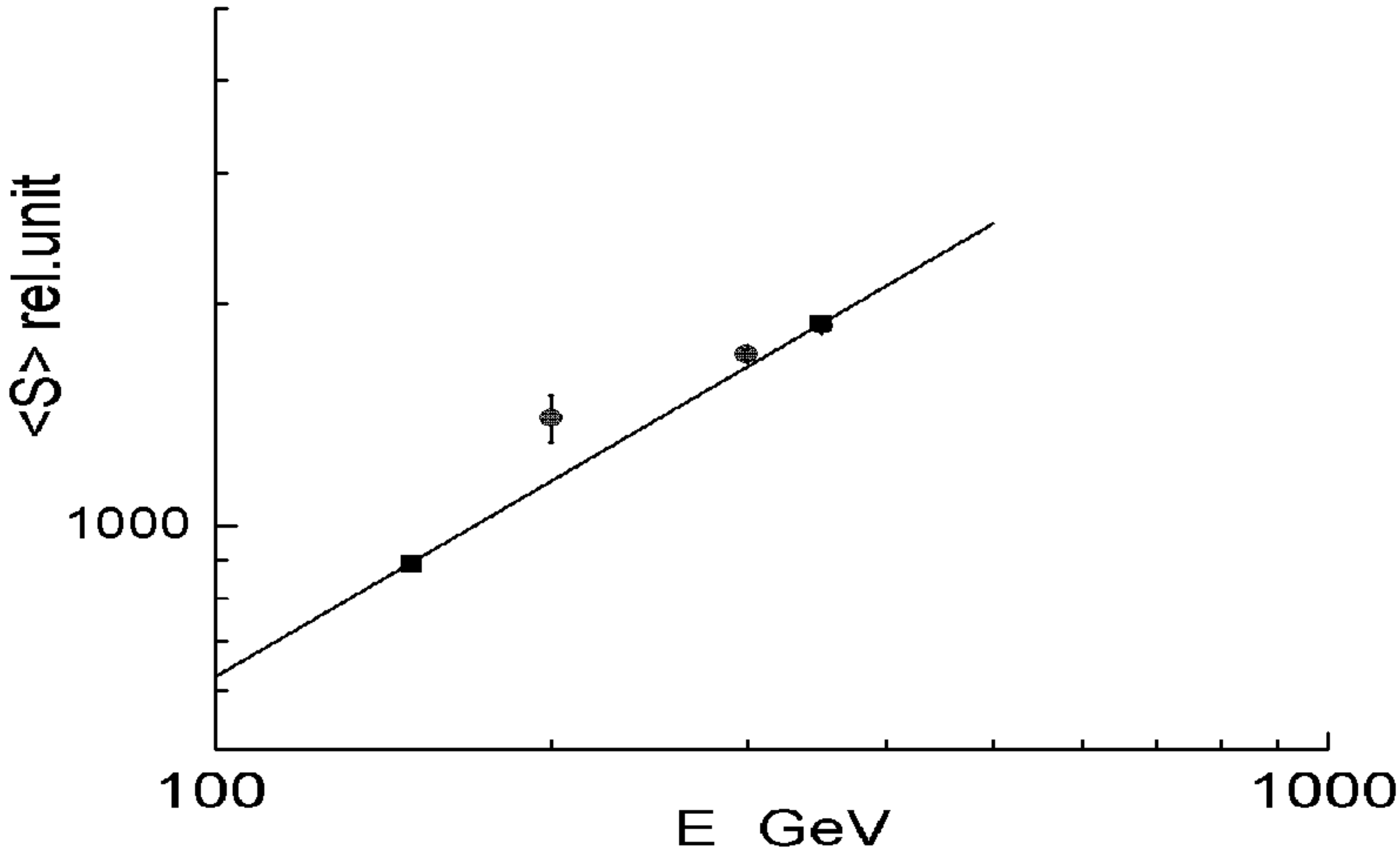
- In the development of the data processing technique we propose to use the S-estimator for the energy determination:

- $S=\Sigma I_i \ln^2 (2H/x_i)$

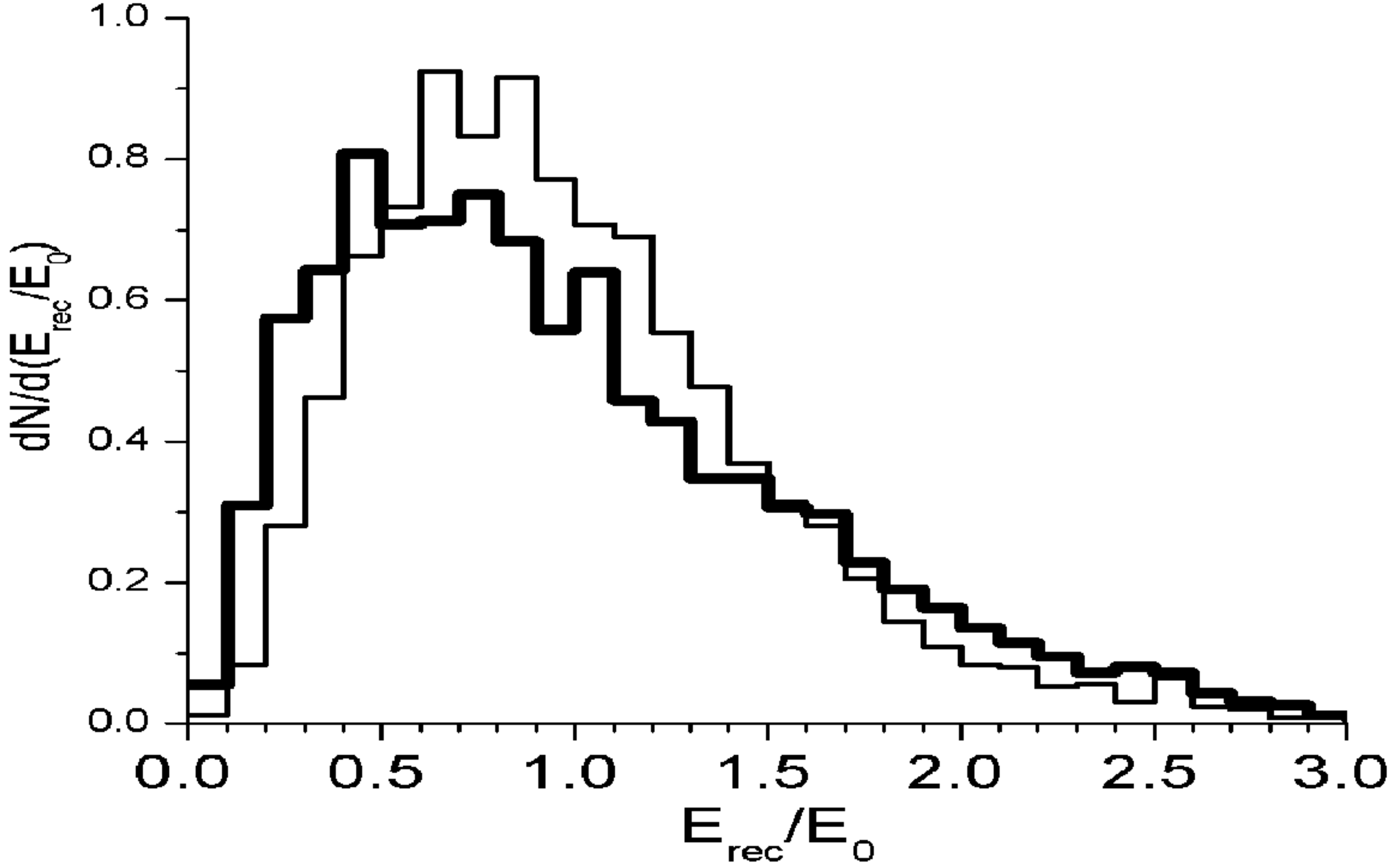
- The direct simulation shows that the rms deviation of reconstructed energy is near 70% . On the one hand S-estimator characterizes the distribution of secondaries on emission angles being sensitive to the Lorentz-factor of the primary particle, and on the other hand S is proportional to the multiplicity of secondaries produced in the target and multiplied in the converter. The contribution of slow neutrals is eliminated by the squaring of η. The simulation showed the simple semi-empirical power law energy dependence for $S \sim E^{0.7}$.
- The perpendicular projections *xi* and *yi* can be used. It allows to exploit microstrip silicon detectors for spatial measurements.
- The microstrip detectors can register many charged particles per strip. The signal is proportional to the strip ionisation or the number of single-charged particles.

The <*S(E)*> dependence is similar for different types of primary nuclei in the wide range. The detailed simulation was performed. The new method permits the reconstruction of primary energy spectra that may have some peculiarities such as deviations from simple power law. On this basis, the NUCLEON device for primary cosmic-ray measurements in satellite investigations was constructed and tested on accelerator beams.

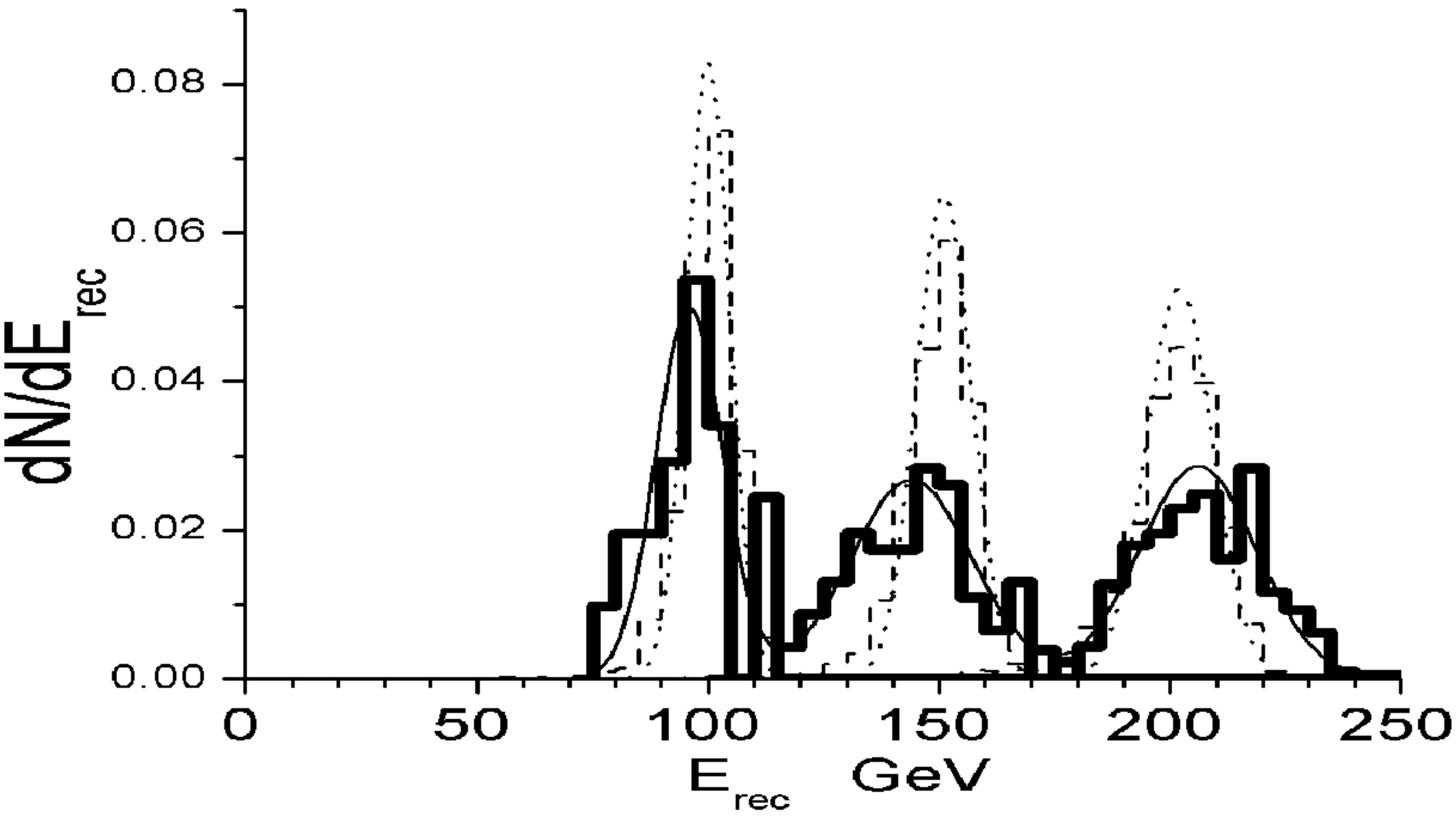
The <S(E)> calibration energy dependence for pion beams in 2012 (squares) and previous 2008 tests (circles)



Normalized reconstructed energy distributions for pion beams of 150 GeV (thin line) and 350 GeV (thick line) (KLEM technique)
RMS~70%



Calorimeter reconstructed energy distributions for 100, 150 and 200 GeV electron beams (solid line) in comparison with simulation results (dashed line) and Gaussian fits for experiment (thin solid line) and simulation (dotted line). RMS~8%



The neural network is used to separate electrons and hadrons.
Error probability dependences on neural network generalized parameter. Probability of electron registration as pion is marked by squares and probability of pion registration as electron is marked by circles.