CHARGE COMPOSITION OF COSMIC RAYS AT ENERGIES MORE THAN 1 TEV BASED ON THE RESULTS OF THE NUCLEON MISSION

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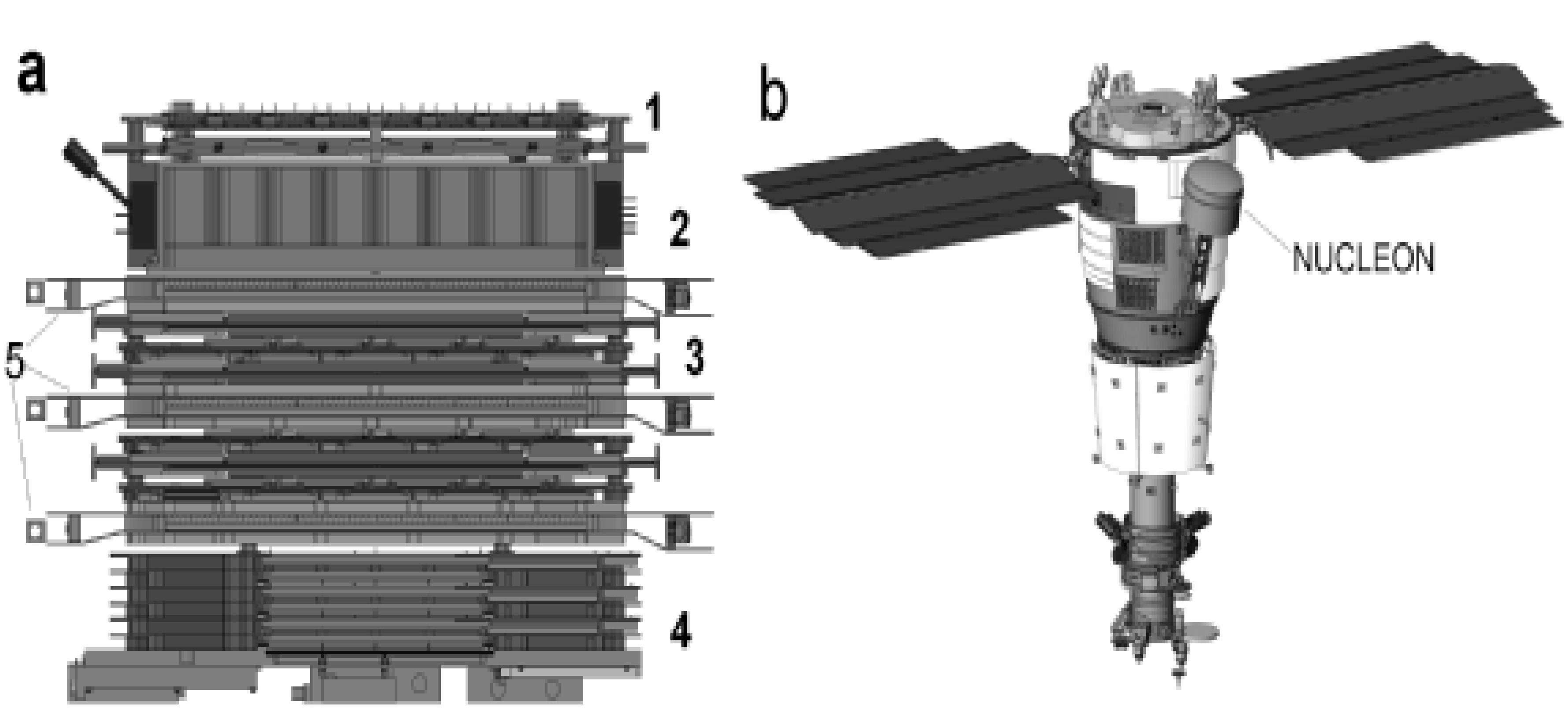
Abstract

The NUCLEON experiment is aimed to investigate composition and energy spectra of high energy cosmic rays. Direct measurements of energy spectra of cosmic ray protons and nuclei at the range of 1-100 TeV are very important for the solution of a general astrophysical problem of origin of cosmic rays. The satellite was launched in 26 December *2014*. The measured charge composition is analyzed and compared with data obtained by other experiments at lower energies. The proton to helium ratio is close to constant at the wide magnetic rigidity area (3-100 TV). The charge composition dependence on magnetic rigidity can be explained by means of the single source model .

NUCLEON



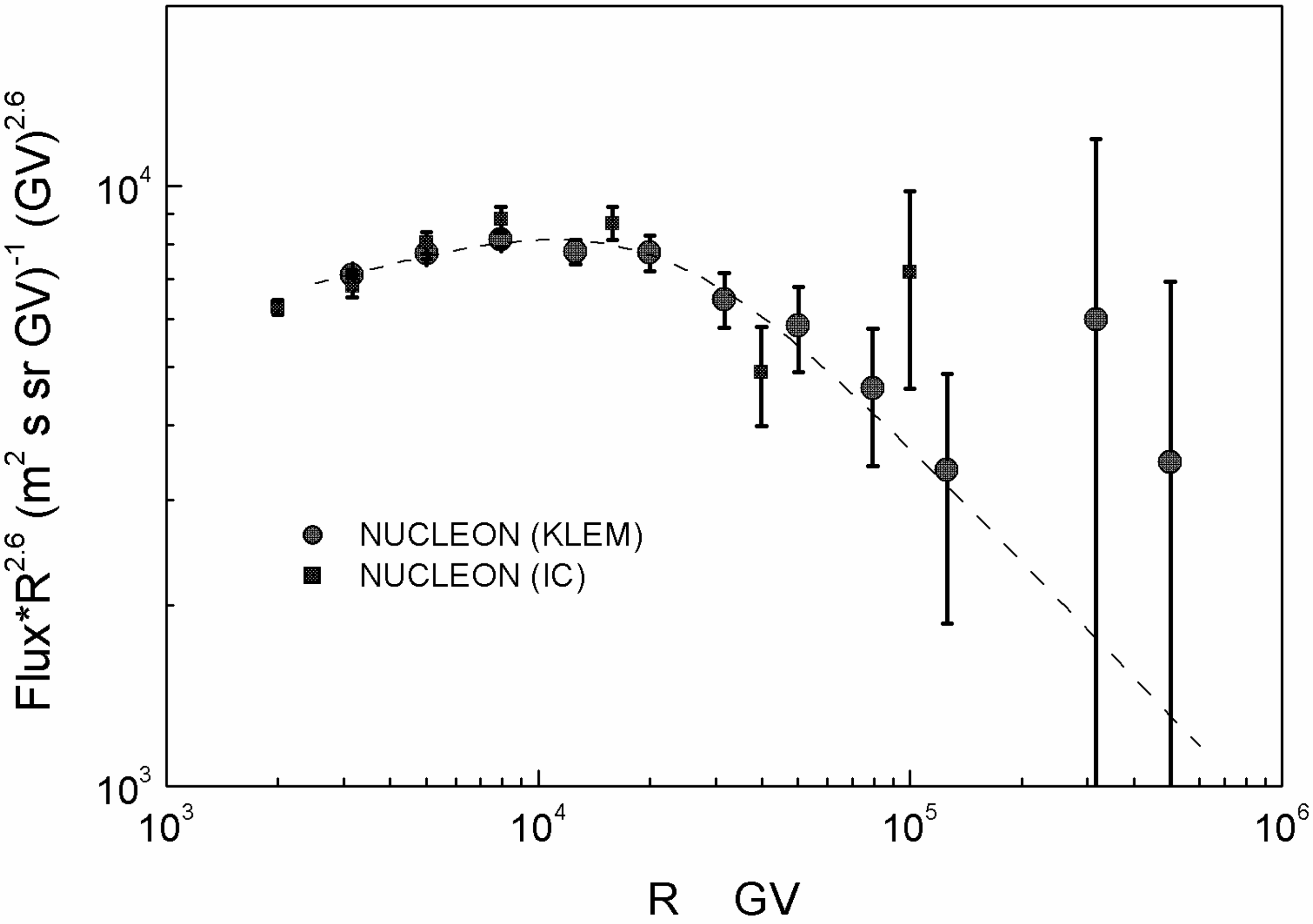
Cosmic ray spectra

- The main mechanism of cosmic ray acceleration is diffusive shock acceleration at the shock-wave fronts in Supernova remnants. The simple models predict smooth power spectra with close spectral indices for different nuclei at wide energy range. However for a long time significant differences between spectra of different components are observed by various experiments.
- For example, the considerable energy dependence of the proton to helium ratio observed for example by AMS02 experiment. It demonstrates the difference of expenents of spectra at energy range between 100 GeV and several TeV per particle.

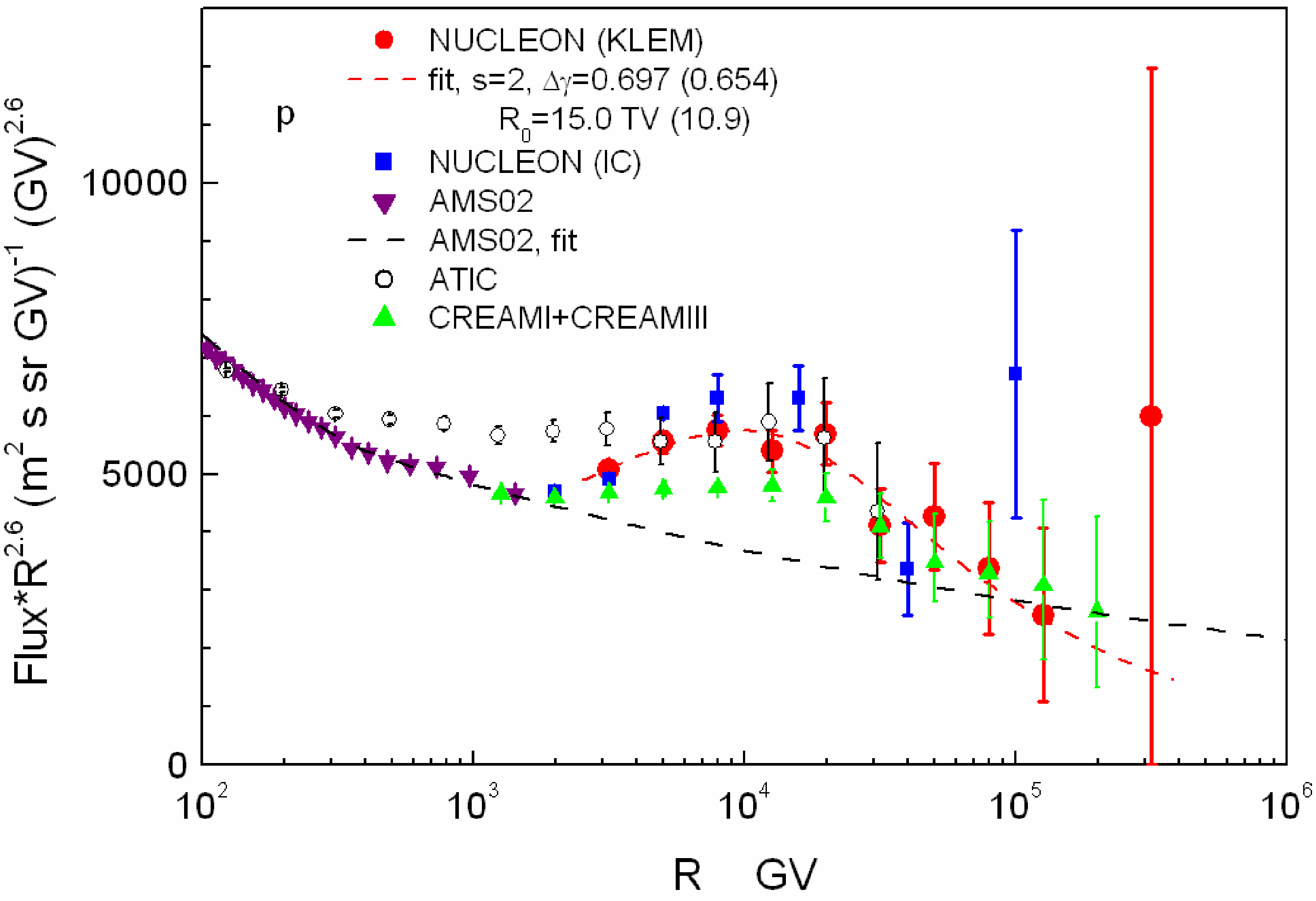
A NEW UNIVERSAL “KNEE”

- The first measured energy spectra of different components allowed to increase the available data in the energy area 1-100 TeV and to obtain first data at energies higher than 100 TeV in direct measurements.
- Statistical reliabilities of components are significantly different. By the analysis of the obtained data it was established that spectra of different components can be described as function of a magnetic rigidity with a break near ~ 10 TV.
- Rigidity spectra of four groups of nuclei were investigated: protons, helium nuclei, the joint heavy nuclei spectrum with charges Z= 6-27, and the all-particles spectrum measured by both IC and KLEM methods.
- Spectra of three groups: p, He, Z = 6-27 are independent from each other. The all nuclei spectrum depends on the first three groups. All heavy-nuclei Z = 6-27 were united in one range of a rigidity as statistics for each separate type of nuclei is still too small for the analysis and, at the same time, the group of nuclei of Z = 6-27 contains all plentiful primary heavy-nuclei. All studied groups of spectra show approximately identical break of a spectrum near a rigidity 10 TV that means the universal nature of the "knee"

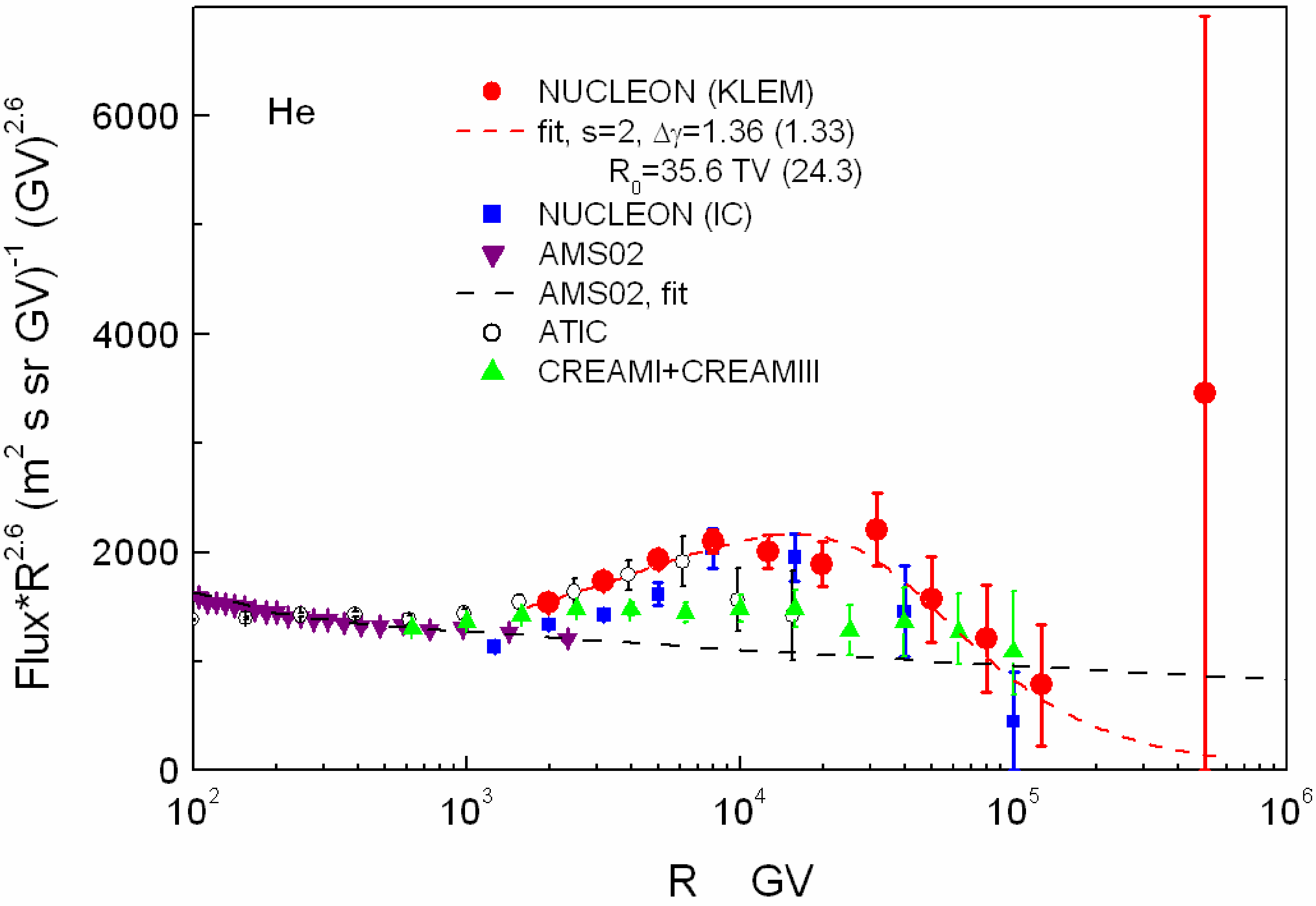
The all particles rigidity spectrum



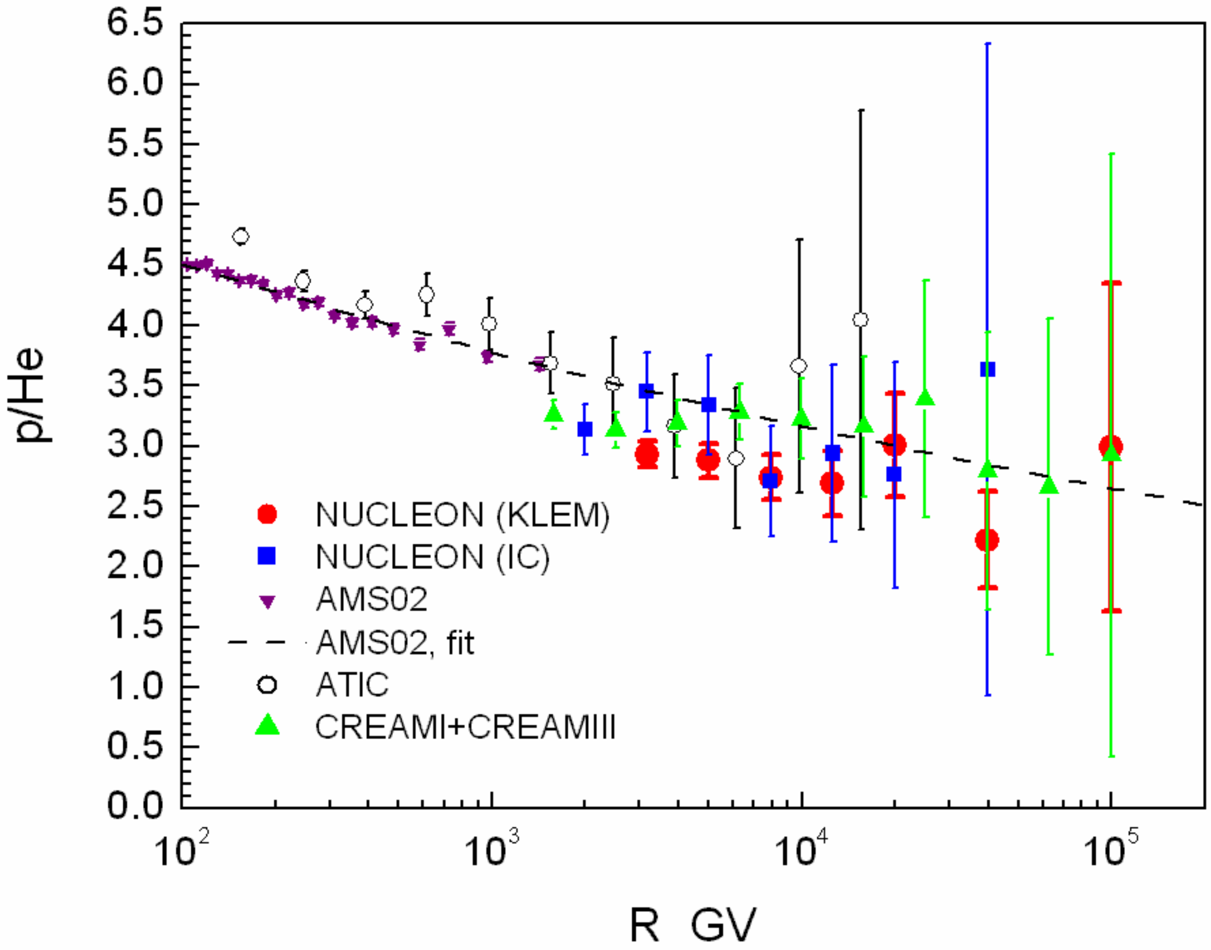
The proton spectrum



The helium spectrum



Proton to helium ratio



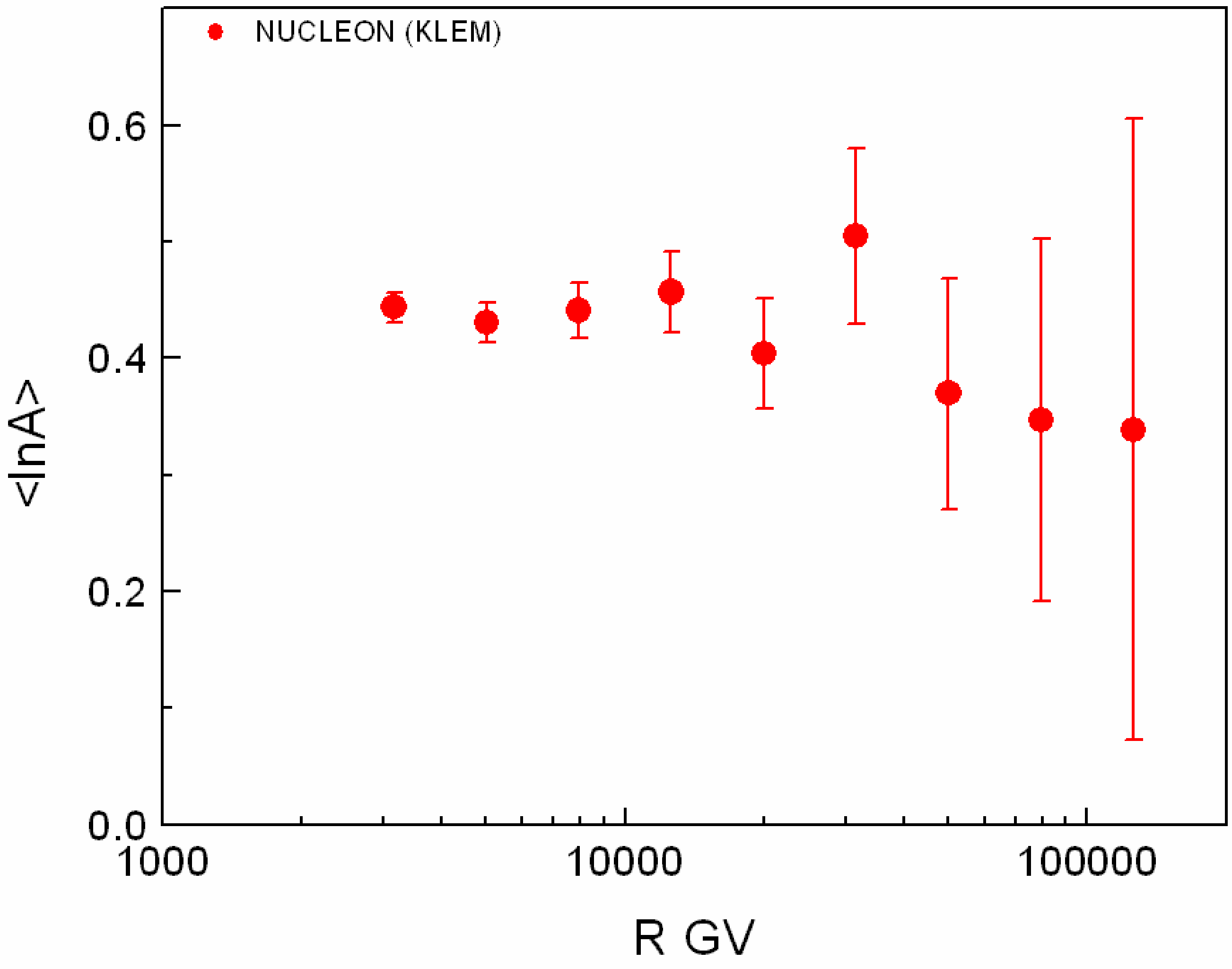
The astrophysical model

- The problem is actually even more interesting. V. Zatsepin and N. Sokolskaya, based on older data in their paper [V. I. Zatsepin and N. V. Sokolskaya. Astronomy and Astrophysics, 458, 1 (2006)] suggested that the break in the spectra of protons and helium has a universal nature in the sense that it takes place in the spectra of all nuclei near the same magnetic rigidity.
- This break can be associated with a certain type of cosmic ray source, which had an acceleration limit near 10 TV. A phenomenological three-component model of the spectra of cosmic rays can be applied.

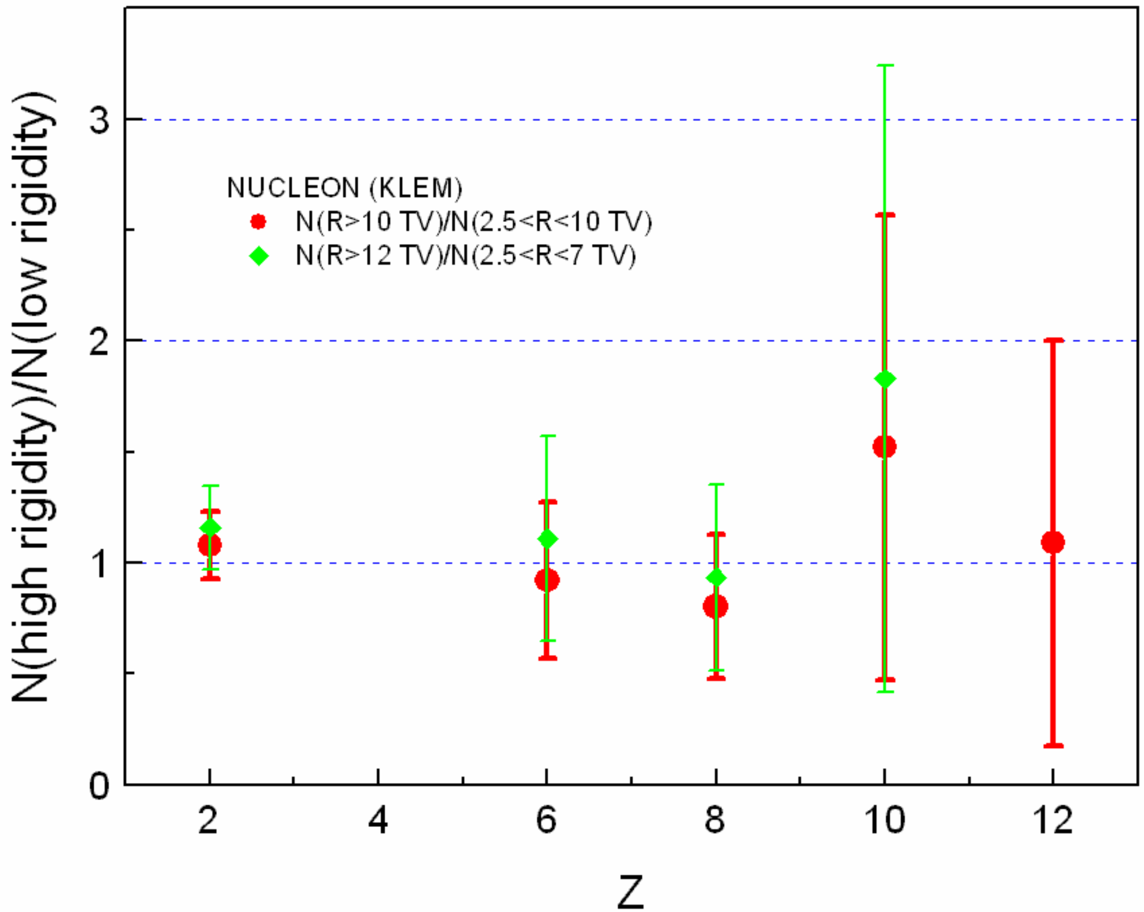
THE CHARGE COMPOSITION

- There are different astrophysical models predicted different breaks in cosmic ray spectra. If the break is caused by transition from a source of one type to a source of other type with other chemical composition, then the chemical composition of cosmic rays has to be changed near the break too.
- We used the mean logarithm of the mass number as function of the magnetic rigidity to evaluate the possible change of the chemical composition.The chemical composition is not changed in the break area within statistical errors.

The mean logarithm of the mass number as function of the magnetic rigidity



The cosmic ray chemical composition can be characterized by the separate nuclei to protons ratio at different values of rigidity. This dependence confirms the constancy of chemical composition at rigidities 2.5-100 TV



The comparison with AMS02 data

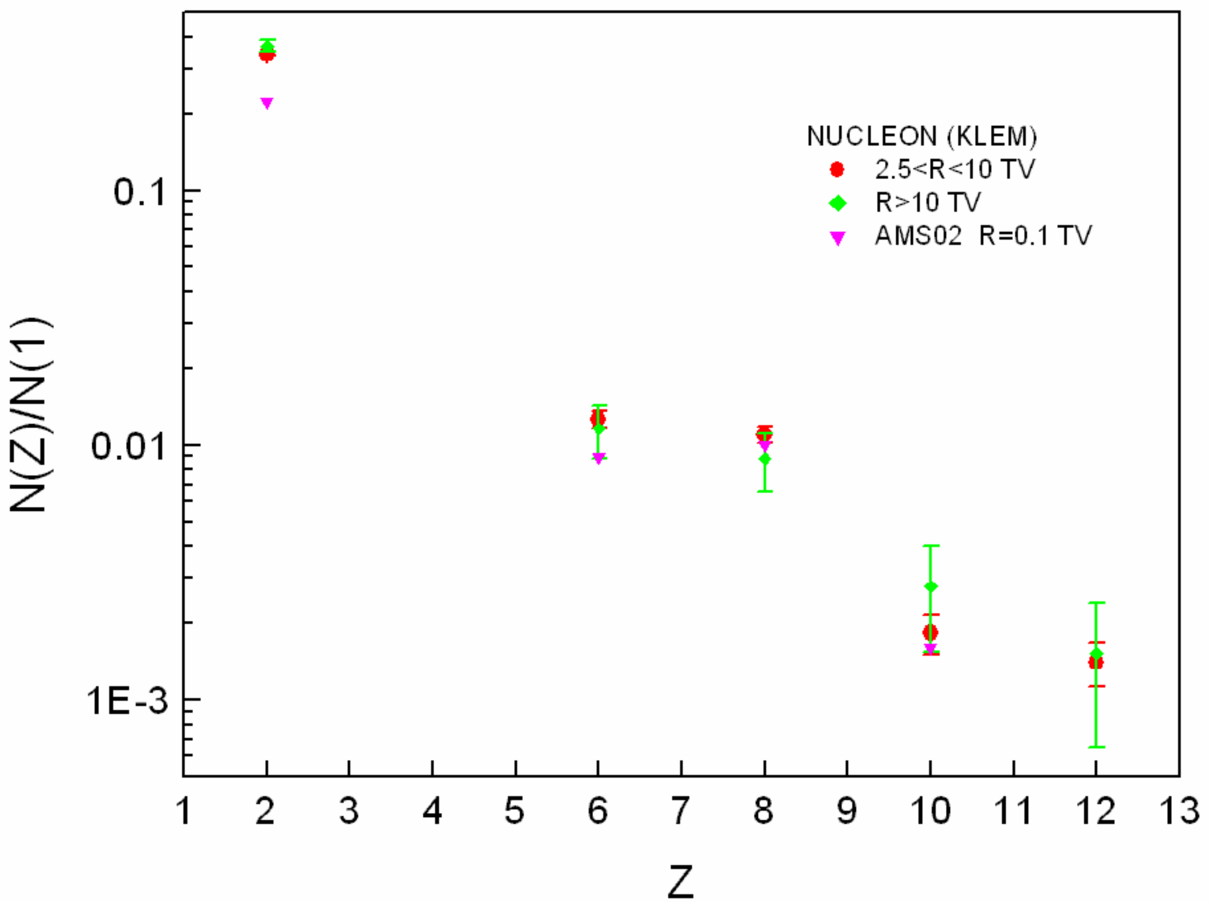
- The charge composition at the break area is significantly different in comparison with composition at rigidity ~100 GV measured by the AMS02 experiment [M.Aguilar, D.Aisa, B.Alpat et al. Phys. Rev. Lett. 115 (2015) 211101; M.Aguilar, L. Ali Cavasonza, B.Alpat et al. Phys. Rev. Lett. 119 (2017) 251101].
- The main difference is the large part of helium at the break area. The helium to proton ratio values are equal to 0.343±0.07 (2.5<R<10 TV), 0.368±0.021 (R>10 TV) and 0.224±0.01 at ~100 GV.

CONCLUSION

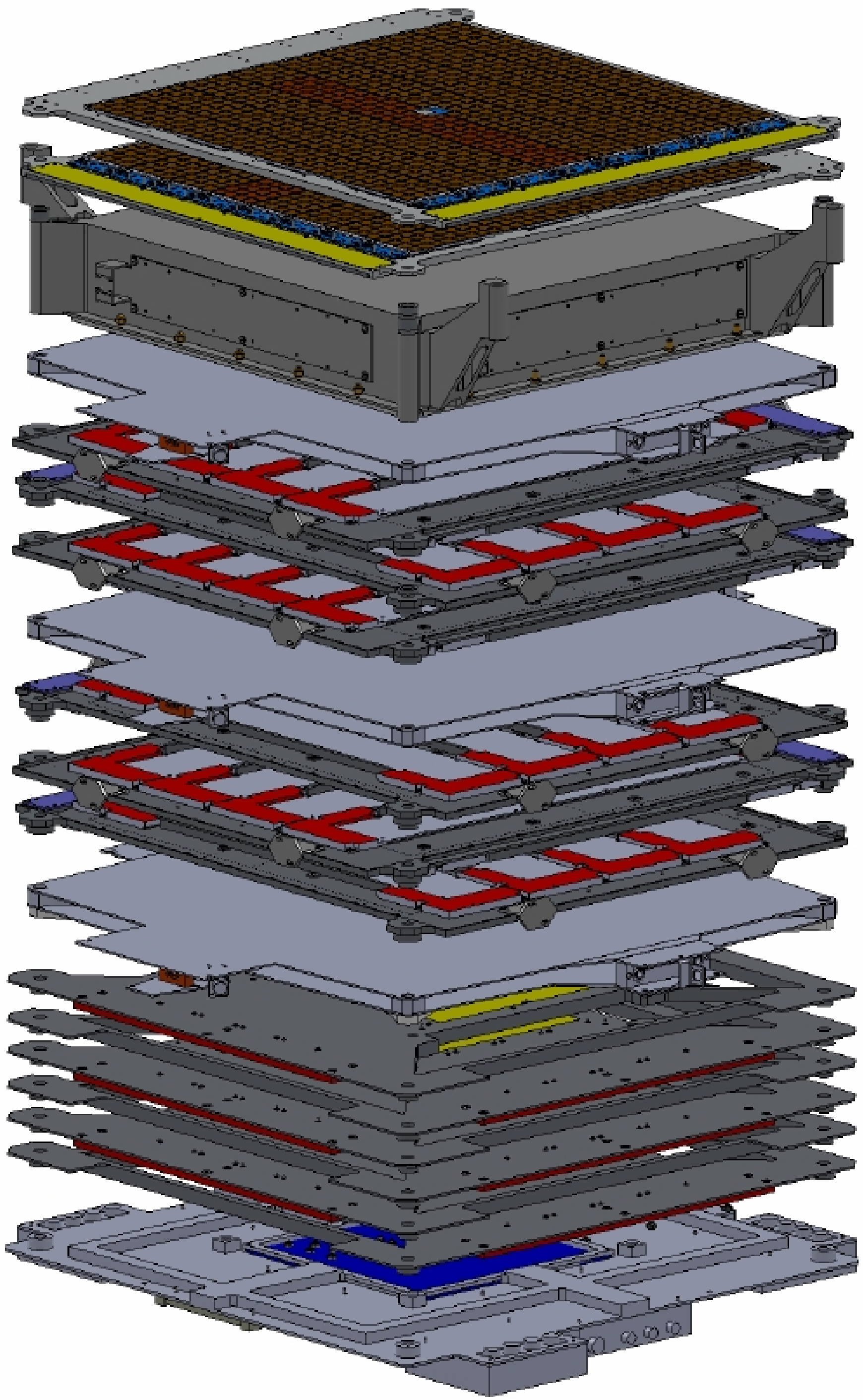
- The charge composition of cosmic ray is close to constant at the new break rigidity area (2.5-100 TV).
- This composition is different from the low rigidity composition measured by the AMS02 experiment.
- It can be interpreted by means of a single source model.
- The charge composition at the break area corresponds to chemical composition of this single source with higher helium content.
- The spectral hardening at 200-300 GV measured by AMS02 can be caused by transition from the Galaxy background to this single source.

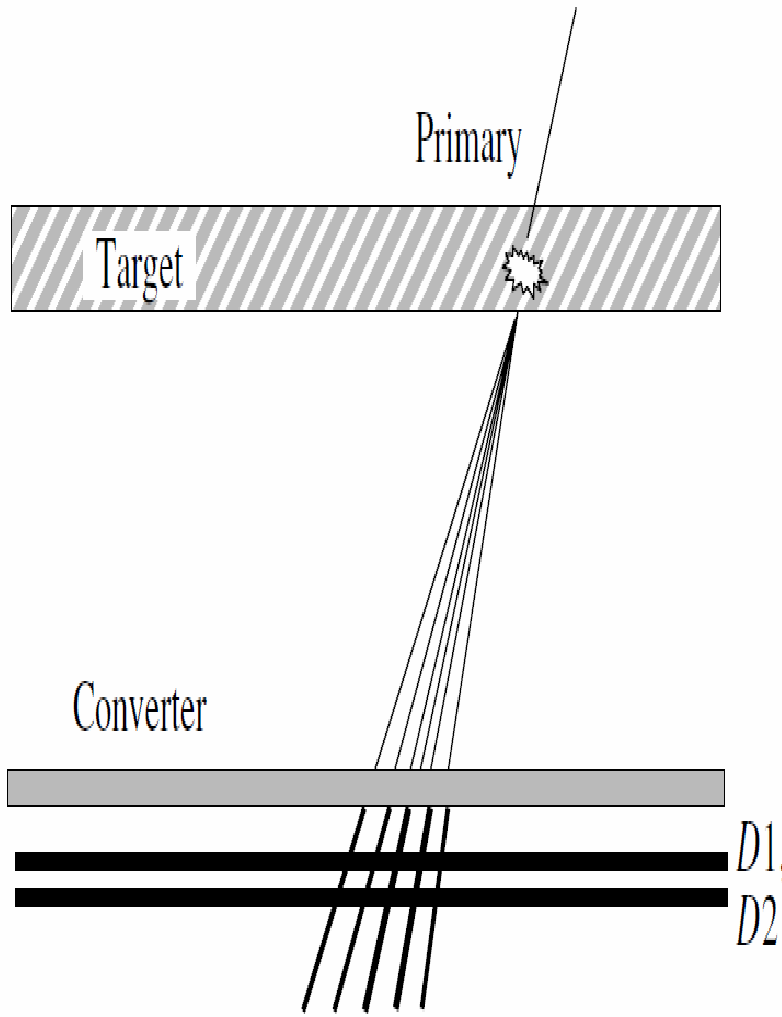
BACKUP SLIDES

CHARGE COMPOSITION

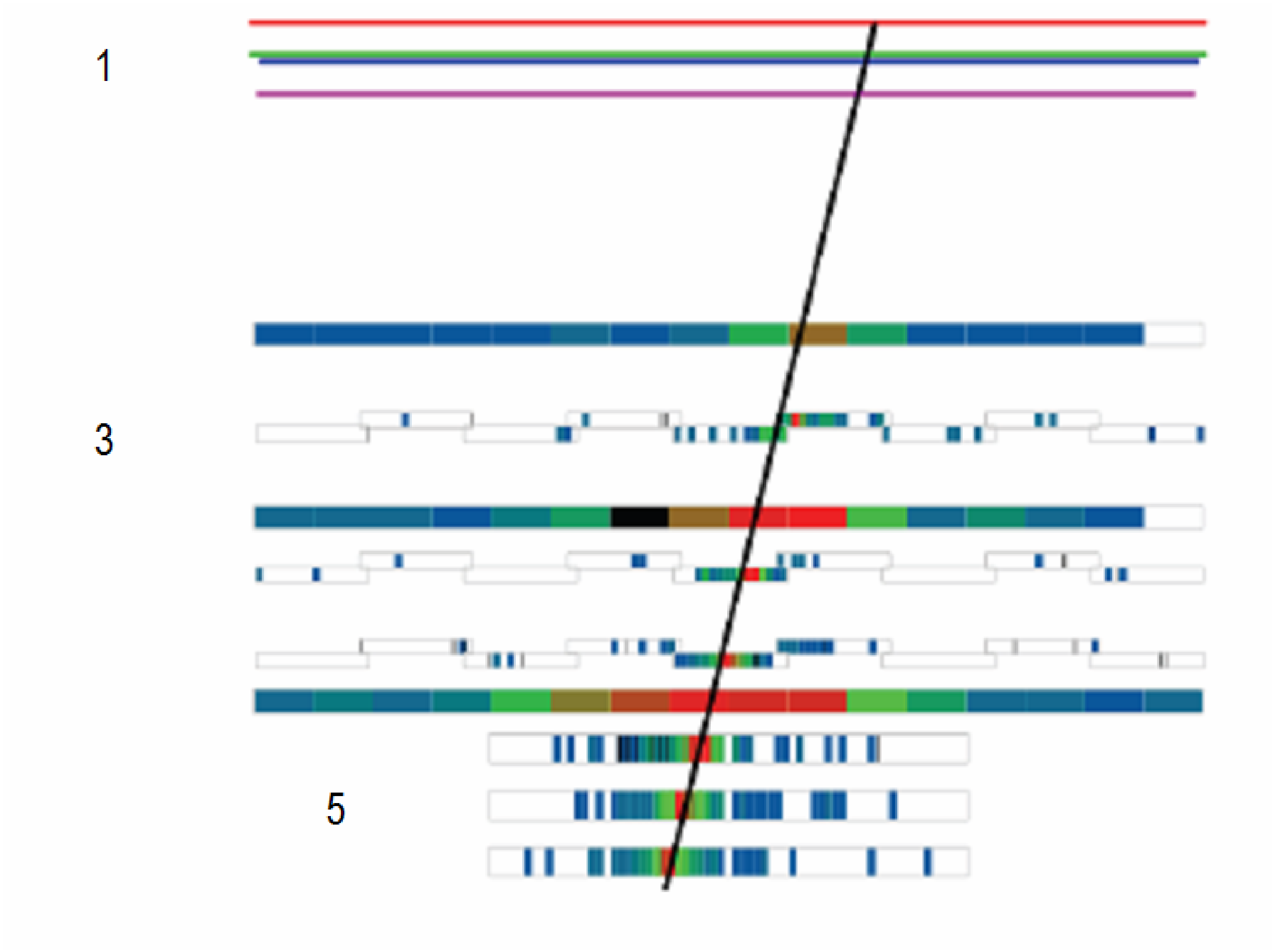


KLEM (Kinematic Lightweight Energy Meter)

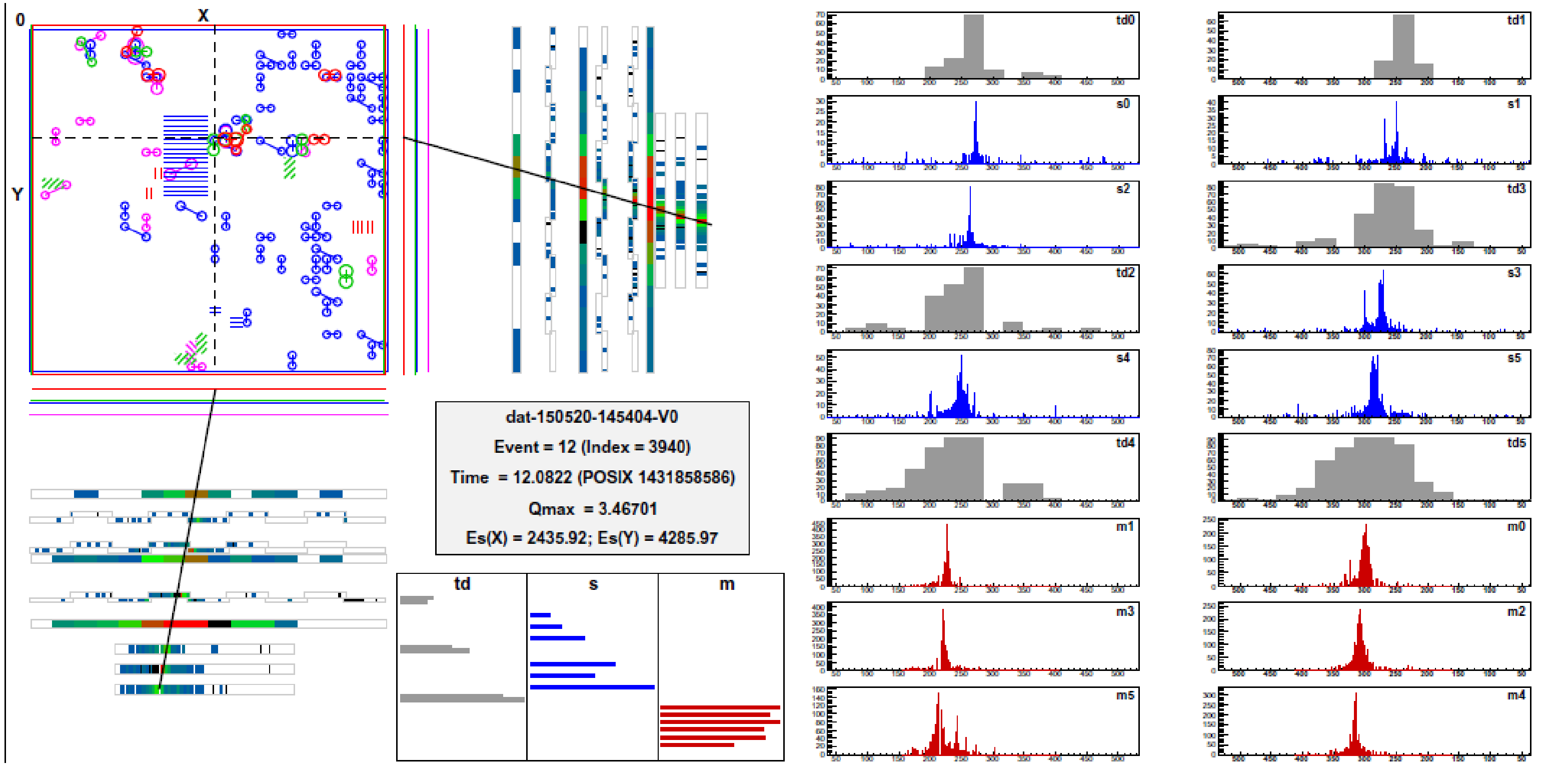




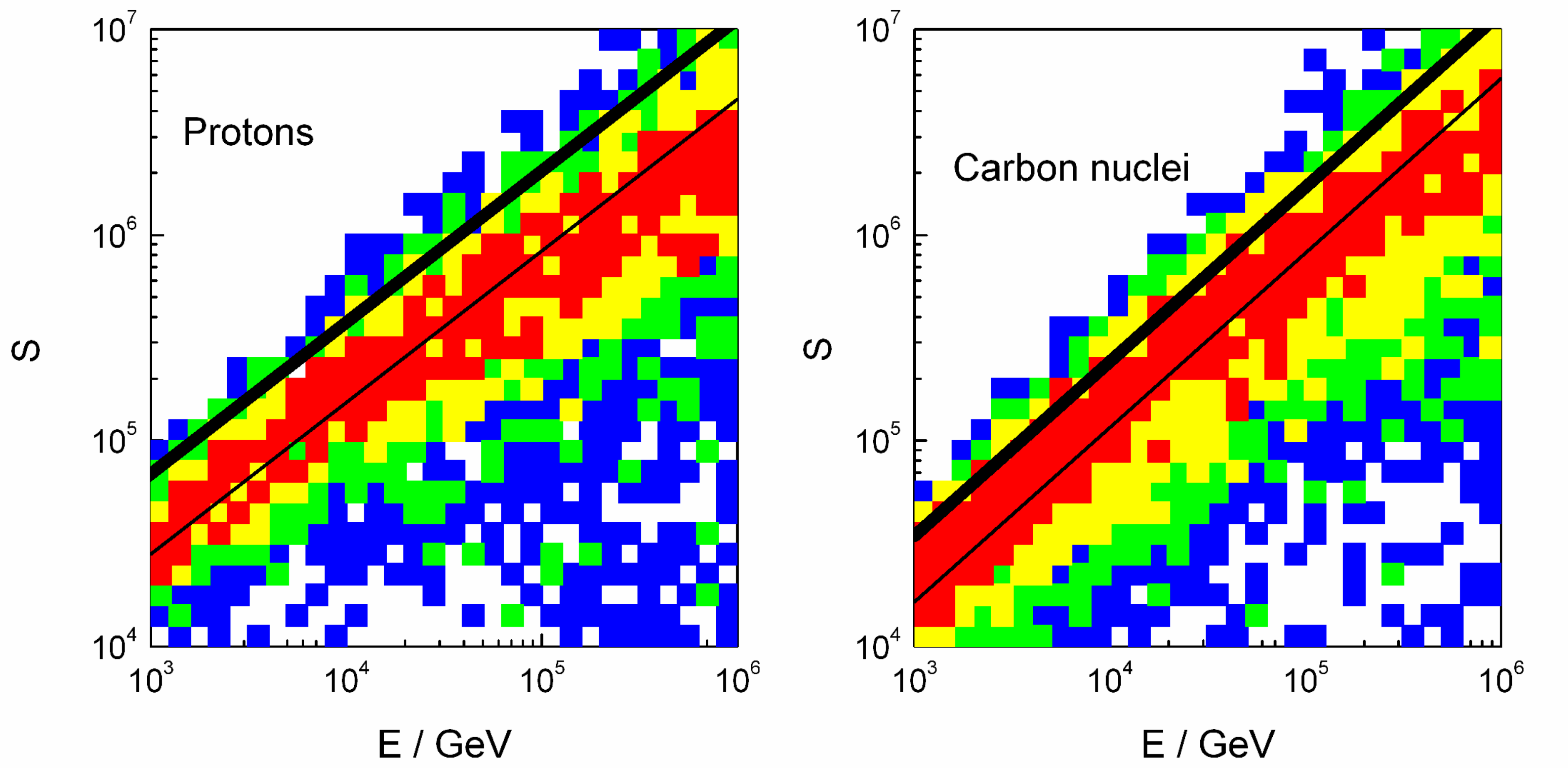
The image of the event. The nucleus initialized the shower. (1) - two pairs of charge measurement system planes; (3) - 6 planes of energy measurement system utilizing the KLEM technique; (5) - calorimeter



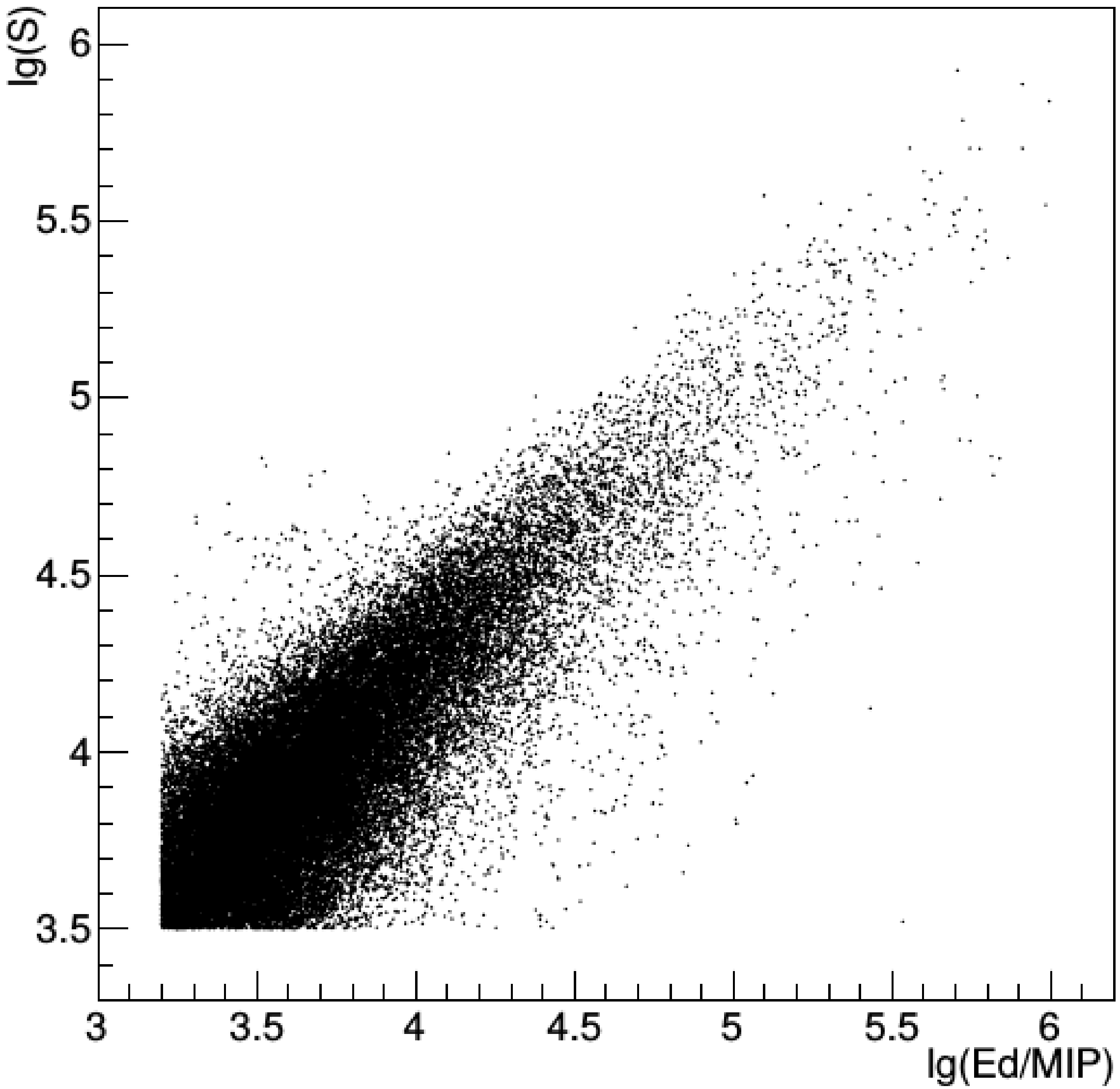
The image of the event. The nucleus initialized the shower



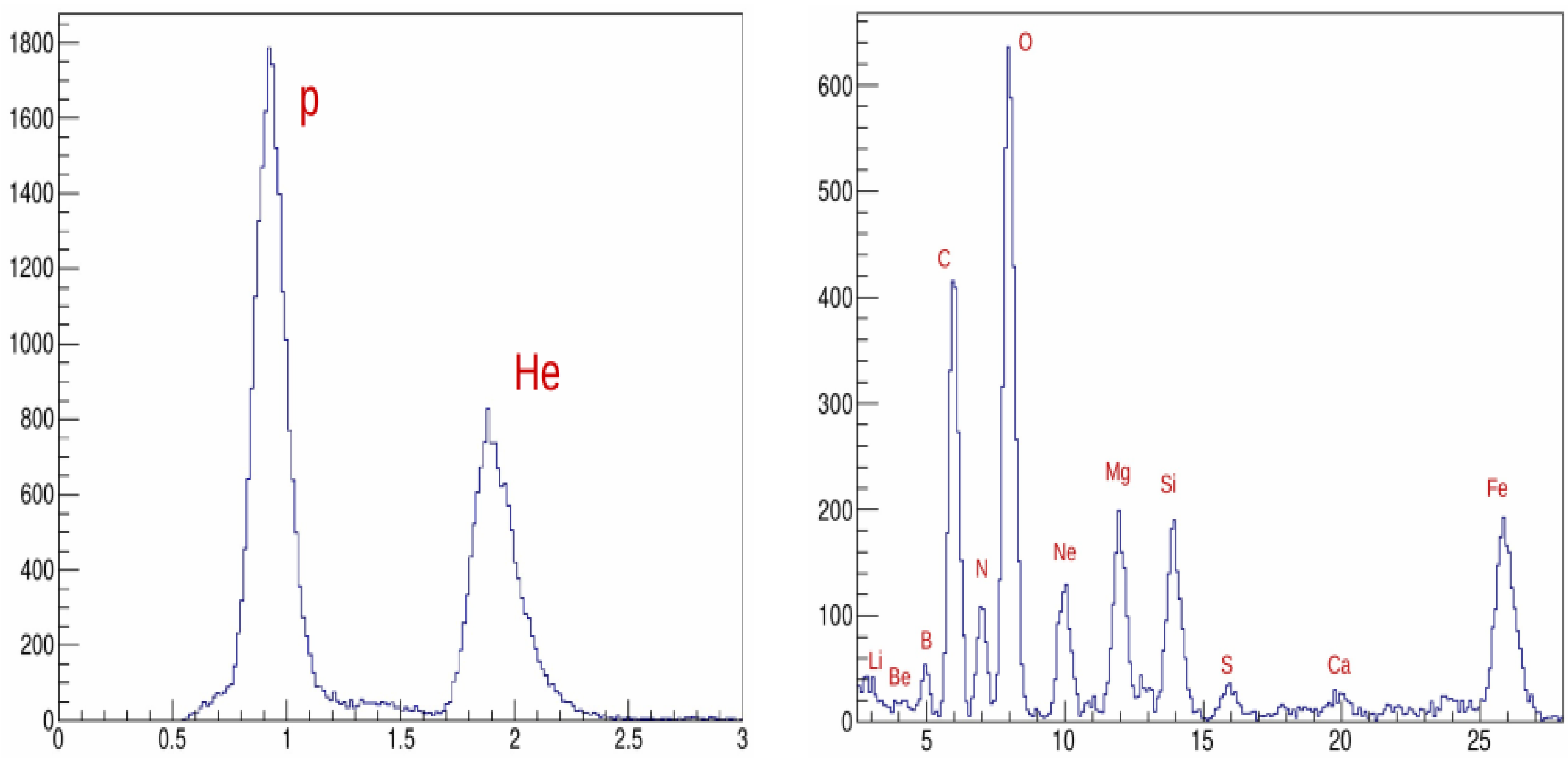
The S-estimator is defined as:
$S=\Sigma I_k \ln^2(2H/x_k)$



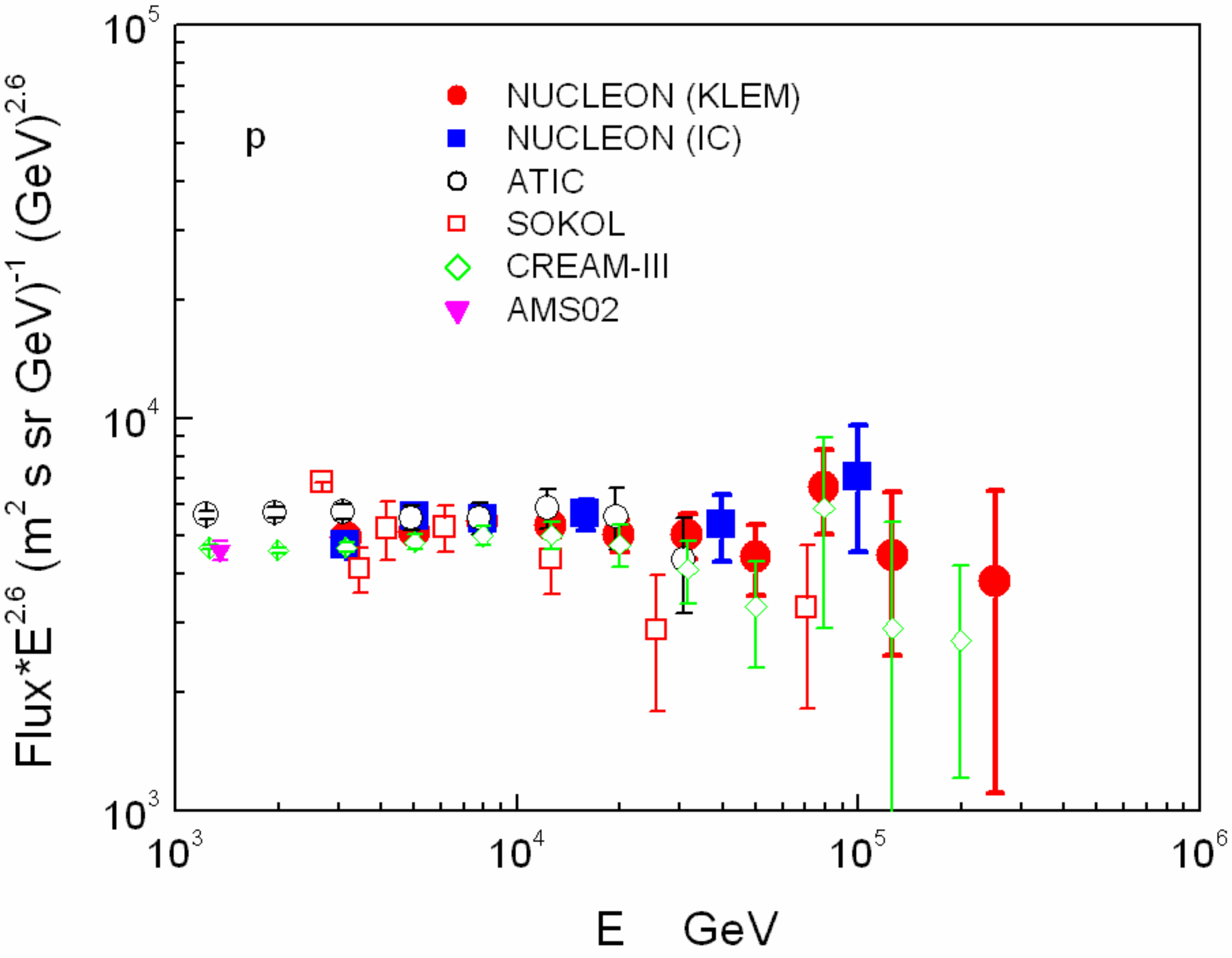
Calorimeter energy deposition vs S estimator (experimental results)



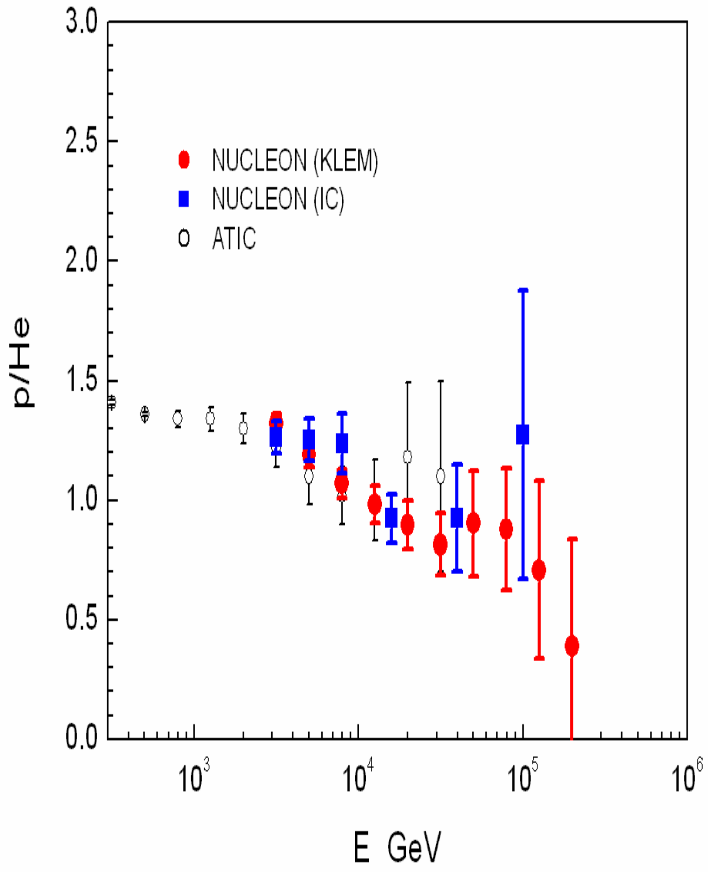
Preliminary charge distribution obtained by the NUCLEON experiment. The resolution is near 0.2 charge unit.

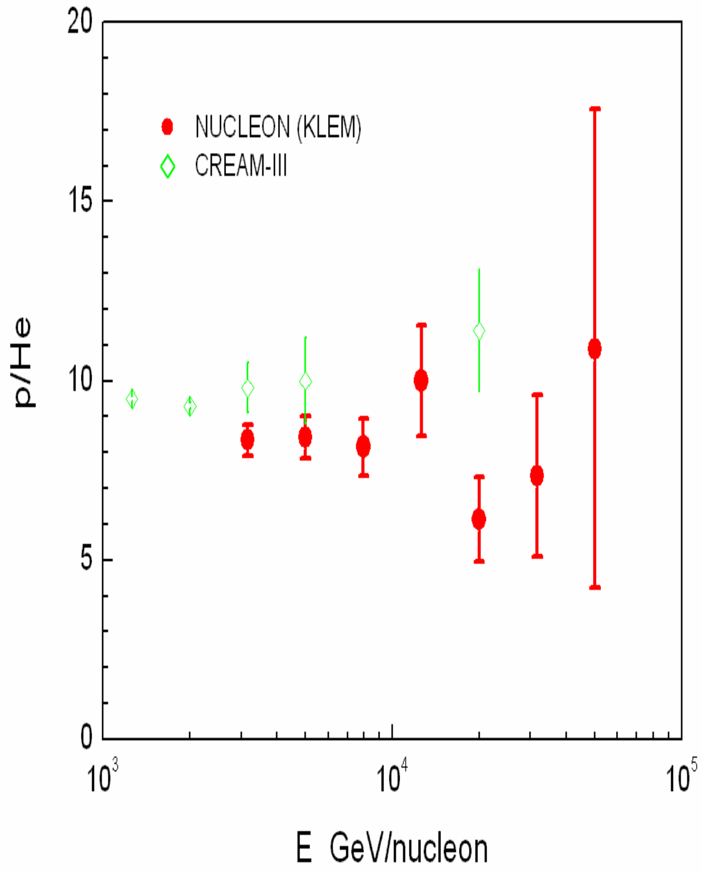


Proton spectra

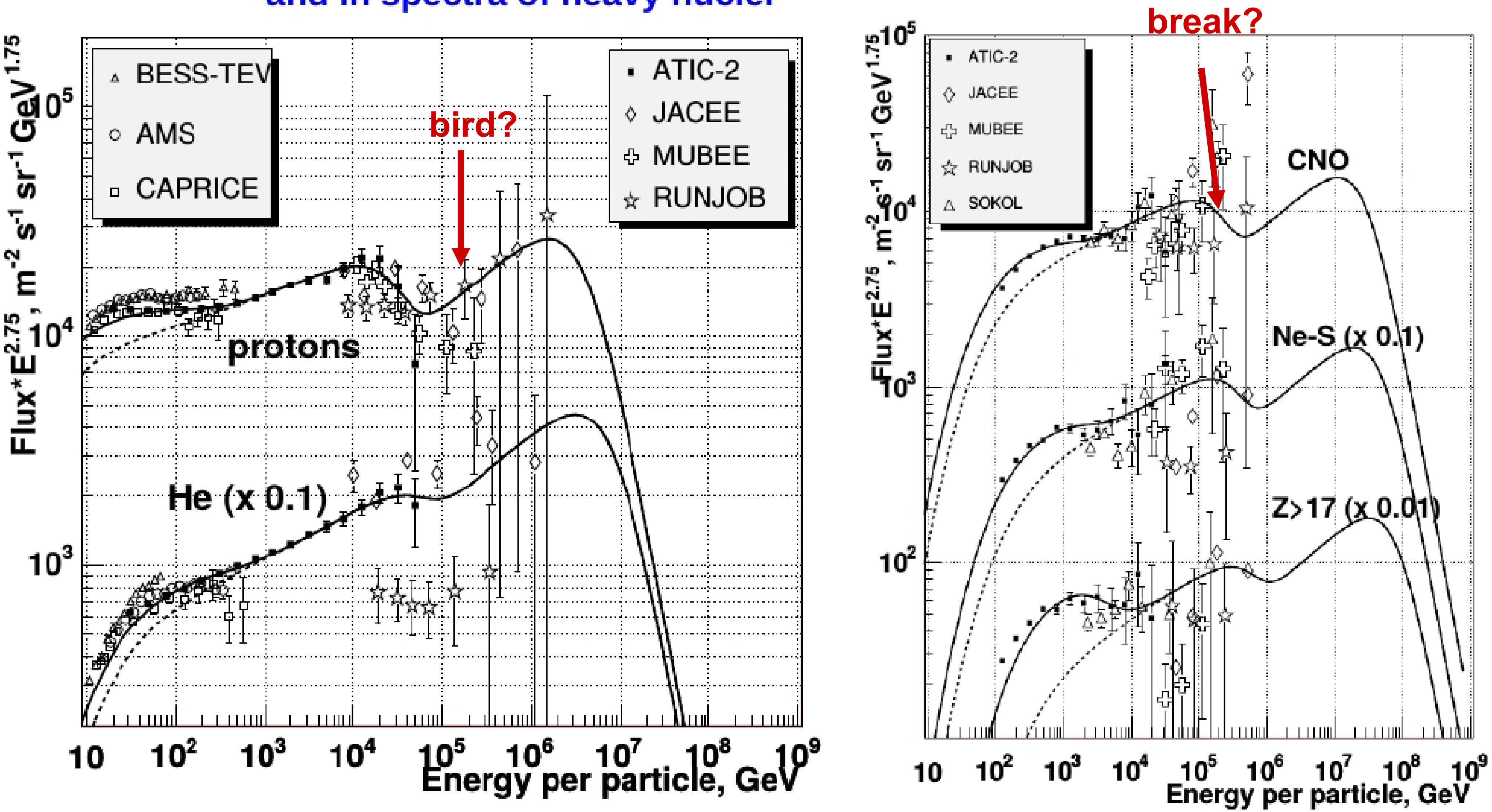


p/He ratio


3.0
2.5
2.0
1.5
1.0
0.5
0.0
p/He
NUCLEON (KLEM)
NUCLEON (IC)
ATIC
10^3
10^4
10^5
10^6
E GeV


20
15
10
5
0
p/He
NUCLEON (KLEM)
CREAM-III
10^3
10^4
10^5
E GeV/nucleon

Zatsepin & Sokolskaya model predicts breaks near R = 10 TV both in spectra of protons and helium, and in spectra of heavy nuclei



V.I. Zatsepin and N.V. Sokolskaya.
A&A, V.458, 2006, pp.1-5


The satellite was launched 28.12.2014.

Rigidity spectra. The possible break near R~10 TeV/Z

		spectral exponents	$\Delta\gamma$
p	R<10 TV	2.50 + 0.05	2.0σ
p	R>10 TV	2.68 + 0.07	
He	R<10 TV	2.33 + 0.02	2.3σ
He	R>10 TV	2.54 + 0.09