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The new method of primary cosmic ray studies in super wide energy range 10^{10}-10^{16} eV.

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Abstract.

An absolutely new approach for the investigation of high energy cosmic rays nuclei (E>10^{11} eV) is proposed. The method is based on measurement of a primary particle energy by determining the spatial density of flux of secondaries produced in a target layer and strengthened by thin converter layer. The proposed technique can be used in the wide range of energies being investigated (10^{10} –10^{16} eV) and gives an accuracy about 60% in the energy determination in an individual case. Ways are outlined to construct relatively light device with large geometric factor, appropriate for studies of chemical composition and energy spectrum of primary cosmic ray.

1 Introduction:

The study of the cosmic rays (CR) flux characteristics in high energy range (>10^{11} eV) is one of the fundamental and important problems of high energy astrophysics. The most valuable information can be obtained by direct measurements, when a real primary particle is detected. In the energy region E>10^{15} eV direct investigations of CR have not been made up to now. Our knowledge about the CR spectrum is based on indirect data - first of all on the EAS technique. In this region almost all investigators indicated a “knee” in the CR primary spectrum at energy of ~3x10^{15} eV. The main problem of direct measurements of high energy CR is that though there are a lot of techniques in the modern experimental physics, only an ionization calorimeters (IC) can be used to perform energy measurements simultaneously for all types of nuclei (Z=1 ÷30) with unified technique (that is very important for determination of their intensities relationship) in a wide energy range (several orders). However the development of the IC technique for the region of higher energies (>10^{14} eV) requires a significant (of several tons) mass of absorber to be launched in the near-Earth space, making these investigations very expensive due to strict requirements to the apparatus (see, e.g., the ELIZA (Auriemma J., et al, 1989), OMEGA-M (Grigirov N.L., et al,1997) and ACCESS (Esbiert J. et al, 1997) projects). Together with the IC technique, for the investigation of high and superhigh energy CR it is possible to use so called kinematic methods of energy determination. They are based on the detection of the emission angles of secondaries produced in inelastic interaction and giving information about the Lorentz-factor of a primary particle. In contrast to the IC, this technique does not require thick absorber, as a thin target is sufficient. Kinematic methods get new impulse for their development in the emulsion experiment RUNJOB(Apanasenko A.V., Fujii M., et al. 1997). Unfortunately emulsion technique is also restricted firstly due to impossibility of a long-term (>250 hours) exposure of nuclear emulsions and X-ray films and, secondly, due to very labour-consuming processing of photo materials. So by our opinion, new techniques should be sought. The essence of our proposal is the application of kinematic methods in researches of high energy cosmic rays, using electronic technique for the measurements of emission angles of secondaries. We consider the possibility of construction the detector with relatively small weight at significant geometric factor foreseeing for a long-term exposure and conducting investigations in a wide (several orders) energy range with a unified technique.

2 Method of energy determination by spatial flux density of secondaries:

Taking into account the disadvantages of heavy calorimeters and emulsion chambers usage, we start to develop a combined method, on one hand, based on the measurement of the emission angle of secondary particles, and, on the other hand, using a thin converter as a superthin calorimeter. The principal scheme is following. A primary particle interacts in the target, see Fig.1, where secondary gamma-quanta with energy E_γ and charged particles with energy E_{ch} are produced. The converter of neutral particles - a thin lead layer (h~11 g/cm^2), located at some distance from the target and just in front of the detecting plane, converts almost all secondary gamma-quanta to charged particles due to electromagnetic cascading. The number of output electrons is proportional to E_γ^S. As a gauge of energy we select the appropriate functional

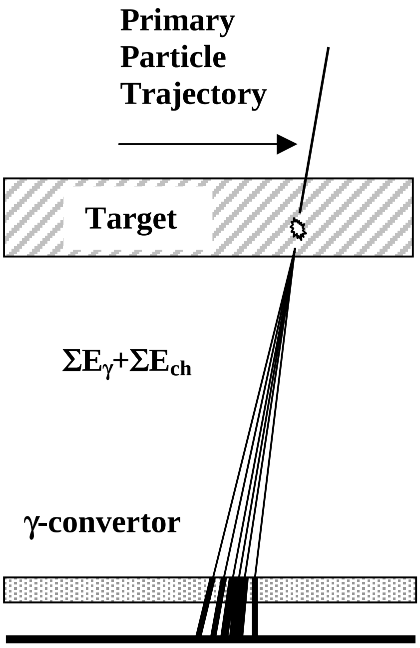

Fig.1. Illustration of method.

$$S(E_0)=\sum \eta_i^2 w_i ,$$

where summation is over the all secondaries detected below the converter. $S(E_0)$ characterises on the one hand the distribution of secondaries on emission angles (or pseudorapidity η) being sensitive to Lorentz -factor of primary and on the other hand proportional to multiplicity of secondaries produced in target and multiplied in the converter. Combination of these two factors allows to obtain simple power law functional dependence on energy per nucleon, universal for all type of primary nuclei in the entire range of energy. It is presented in Fig.2 for proton and carbon nucleus. An accuracy of energy determination in individual event is about ~60%. This simulation was performed with the GEANT program complex, including different hadron-nucleus interactions codes: FLUKA, QGSM (Bashindzhagyan G.L. et al, 1999), (Kalmykov N.N. , 1997).

The method was checked using materials of the mountain experiment (Grigorov N.L. et al. 1969) in energy region E_0=100-600 GeV, where emission angles of secondaries were measured by Wilson chamber and total hadron energy was measured by ionization calorimeter. The application of our method to these data showed the good agreement with energy determined by calorimeter. The experimentally obtained pseudo rapidity distributions of charge particles in $p - \bar{p}$ collisions (Albajar C.A. et al, UA5 collaboration, 1986, Albajar C.A. et al, UA5 collaboration, 1987) are not in noticeable contradictions with QGSJET (Kalmykov N.N.,1997) model predictions for the central of mass energies E_{cm}=200GeV, 540 GeV, 900 GeV, that gives additional grounds for the application of this method in higher energy region.

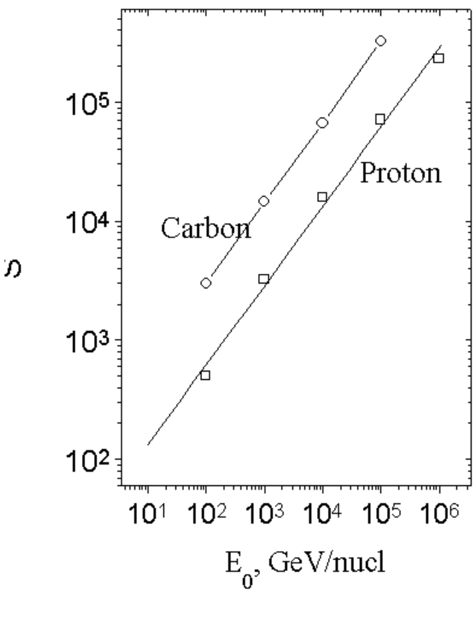

Fig.2. S(E0/nucl) dependence.

3 Device:

The presented method of energy determination seems to be rather promising for investigation of primary cosmic rays onboard spacecrafts due to absence of thick absorber. It is supposed to apply silicon detectors developed in MSU in cooperation with firm ELMA-

PROGRESS (Bashindzhagyan G.L. et al, 1999) for precision determination of a primary particle charge and coordinates of secondary particles. These detectors have charge resolution about dZ~0.1 and the best spatial resolution dx=2-3 microns. After special studies on optimization of detector design we chose one variant according to criteria of the best relation between the weight and geometric factor. The fixed design of a detector is schematically shown in fig.3.

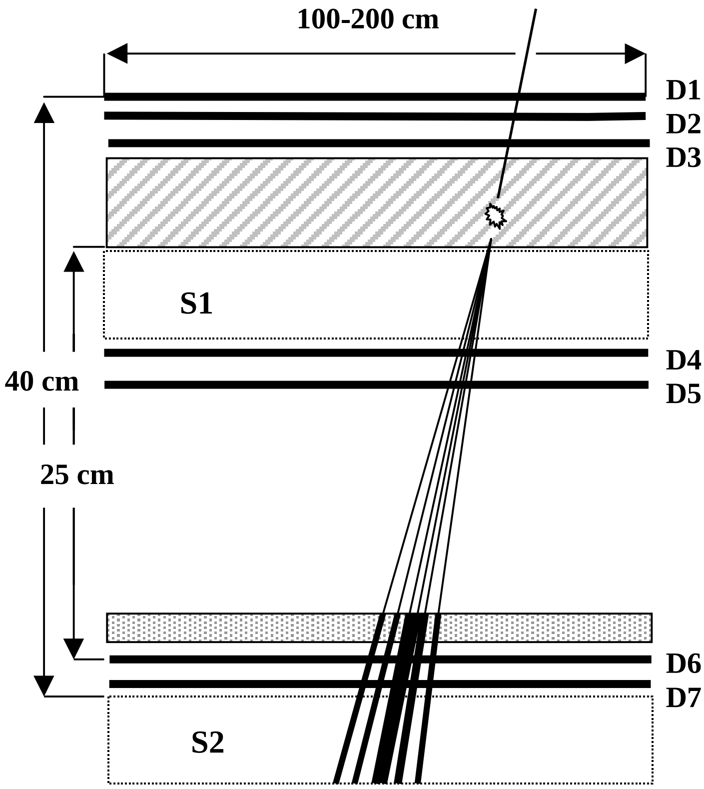

Fig.3 The scheme of device.

7 layers (D1-D7) of silicon detectors by a thickness h ~ 300 microns, 2 layers (S1,S2) of plastic scintillator (h~ 0.5-1 cm), carbon target (h ~ 10 cм) and lead converter of γ-quanta (h~1cm) compose the device structure. D1-layer consists of a pad Si -detectors with the pad size ~ 2x2 cm ^{2} designed for precision measurement of a primary particle charge with achievable resolution dz~ 0.1 of charge unit. Microstrip Si detectors in D2 and D3 layers are placed in perpendicular directions, providing spatial resolution by x and y coordinates about 20 mkm, and designed for to the location of a primary particle trajectory, determination of the shower particle accompaniment in the case of interaction above D1 layer, indication of the back current of particles from the target, duplication of the D1 layer measurements. D4, D5 layers of Si detectors are similar to D2, D3 layer and designed for a primary particle trajectory measurement. Similar D6, D7 layers are mainly designed for the measurement of spatial flux density of secondary particles originated in target and multiplied in converter. The available spatial resolution of these detectors are about 5 mkm. The detectors S1, S2 are intended for prompt trigger elaboration, allowing the analysis of an event. The full Monte-Carlo simulation performed taking into account the processes within strip detectors showed, that the proposed construction of the device allows to make a precision measurement of a primary particle charge and the spatial resolution of position sensitive strip detectors practically does not influence on an energy resolution (i.e. do not introduce distortions to the dependence presented in Fig.2).

The efficiency W of registration of different nuclei incident upon the chamber at average angle was calculated in the frames of QGSJET model: W~ 40 % for protons , ~80% for C nucleus, 98% for Fe nucleus at energy ~ 1PeV. The structure of the proposed device allows module composition - a base module with dimensions 1x1x0.4 m^3 is constructed, the module is launched beyond the atmosphere and the experiment starts. The energy investigated in the experiment becomes higher and higher with increasing number of such modules in the orbit. In Table 1 we present the expected weight, geometric factor G, exposure factor F=G*T*W for one year exposition T for different numbers of blocks of planned device. In the last column there is a very important characteristic: the number of readout channels basically determining the total power consumption during the flight. The minimum necessary power consumption per one channel should be not more than 2 mW, otherwise there can be serious obstacles for operation of the device during the flight onboard the spacecraft. In this case even for device of 4m^2 square (see Table 1) the total power consumption will be 400 W.

Table 1

Square of detector	Weight .	Geometric factor G m^2 str	Exposure Factor F m^2str year for protons	The number of readout channels
$1m^2$	350 kg	1.5	0.59	50000
$2m^2$	700 kg	3.7	1.59	100000
$3m^2$	1050 kg	6.2	2.54	150000
$4m^2$	1400 kg	8.7	3.62	200000

4 Discussions:

It is obvious, that the unambiguous interpretation of the "knee" phenomenon in a primary cosmic ray spectrum in the field of energies 10^{15} -10^{16} eV can be obtained only providing sufficient body of a statistical material within the fixed range. If suggesting the lower threshold of such necessary body is more than 10 events with energies more than 10^{16} eV, and basing on intensity determined in EAS experiments 2.5-3 particles per (m^2 str year) with $E>10^{16}$ eV, one can estimate the necessary factor of exposure as F > 4 m^2str year. Assuming, that the cosmic ray spectrum consists of protons only (minimum value of W) and time of exposure will be not less than 3 years, it is possible to conclude using data from Table 1, that the device with square $2m^2$ and weight 700 kg is sufficient for the primary spectra measurement in the "knee' region.

By our opinion it is expedient to start researches by proposed methods with small and chip apparatus (weight less than 20 kg, dimensions less than 20x20x30 cm^3), aimed to the region 10^{11}-10^{14} eV. Besides independent research meaning, such experiment would be necessary stage of real onboard testing of proposed technique.

Such project (''TUS-M project") is suggested to be realized in nearest future at Russian Segment of International Space Station (Collection articles , 1999).

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