COMPLEX INSTALLATION HADRON-55 FOR REGISTRATION OF WIDE ATMOSPHERIC SHOWERS*

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(Received November 17, 2021; accepted November 17, 2021)

Gamma astronomy is the only experimental possibility of local sources specifying high-energy cosmic radiation (10^{12}–10^{14} eV). In prospect, only neutrino astronomy can supplement the search and study of the galactic and metagalactic objects, where the processes of protons and nuclei acceleration are realized. These processes are accompanied by the generation of gamma quanta and neutrinos, which are not scattered in the magnetic fields of the Universe. Therefore, possibilities of experimental study of the processes and specific stellar objects properties are expanded. Various models and theories of the Universe development are created and tested based on the experimental data obtained in gamma astronomy. Thus, the development of the gamma-astronomical experimental research and observation methods is brought to the fore. The HADRON-55 installation is one of the ground-based gamma-ray detectors that can reliably detect gamma rays with the energies above 1 TeV. In the article, the physical and technical characteristics, the algorithm for registration, and their spatial-energy characteristics of gamma-ray are presented.

DOI:10.5506/APhysPolBSupp.14.681

1. Introduction

The HADRON-55 installation is located at the Tien Shan high-mountain scientific station of cosmic rays at an altitude of 3340 meters above sea level. The complex installation consists of an ionization-neutron calorimeter and the scintillation (SC) detectors located inside and outside the laboratory building [1, 2].

* Presented at III International Scientific Forum "Nuclear Science and Technologies", Almaty, Kazakhstan, September 20–24, 2021.

The two-tier coordinate-ionization calorimeter INCA is included in HADRON-55. The upper tier, called the gamma block, contains two rows of the ionization cameras arranged in mutually perpendicular directions, stacked with plumbums. The lower tier, called the hadron block, contains ten rows of the ionization cameras and one row (fifth) of the neutron counters module arranged with the plumbum and iron absorber.

2. Description of the HADRON-55 installation

The separated gamma and hadron blocks, as well as the neutron detectors row in the calorimeter, allow the HADRON-55 installation to:

— research of the correlations between the primary energy E_0, determined from the measured parameters of the EAS, and the energy transferred to hadrons, neutrons, and electron–photon component as well (calculations show that the correlations are very sensitive to the primary particle nature);

— study the abnormal absorption of hadrons detected earlier in deep plumbum X-ray emulsion cameras of the Pamir–Chakaltaya experiment;

— study the astronomical gamma quanta in the energy range above 1012 eV based on the scintillation method and the usage of the gamma block of the ionization-neutron calorimeter (INCA);

— search for exotic particles and events (such as strangelets and centaurs, characterized by an abnormal ratio of charged and neutral hadrons).

The ionization-neutron calorimeter continues to study the hadron interaction characteristics in the extensive air showers trunks. The gamma and the hadron blocks are installed vertically at 2.2 m from each other. The gamma block consists of two rows of the ionization cameras: 100 cameras in the first row, and 138 cameras in the second, separated by a plumbum absorber. The hadron block consists of the iron absorber with cavities and the fifth row containing the SD-5G neutron and Geiger counters [3]. Ten rows of the ionization cameras are installed in the cavities. These blocks are used to measure the cosmic radiation components energy (electron–photon, neutron, hadron) and to determine the trajectory of the EAS. Two adjacent rows — even and odd — form the observation level. Each of the scintillation detectors measures the particles flux density passed through its area in a wide range. This density is determined by

$$\rho_{\rm sc} = \exp((n-1)/10)/S\,,$$

where S — detector area, n — impulse amplitude code from the detector ($n = 2$–100) [4]. Physical and technical characteristics of the HADRON-55 setup are shown in Table I.

TABLE I

Physical and technical characteristics of the HADRON-55 installation.

Effective area of the HADRON-55 installation	30000 m^2
The area of the ionization — neutron calorimeter "INCA"	55 m^2
Number of rows with detectors	12
"INCA" installation thickness	1200 gm/cm^2
Total number of measuring channels in 11 rows	1140
Dynamic range of measurement of ionization channels	3×105
Energy measurement accuracy	10%
Effective area of the inner carpet of scintillation detectors of the shower subsystem	324 m^2
Number of internal scintillation detectors	30
Number of peripheral scintillation detectors	12
Accuracy of measurement of the trunk angles of wide air showers	0.2 deg
Total electrical power consumption	3 kw

Figure 1 shows the scheme of the HADRON-55 complex installation, contains the ionization-neutron calorimeter, internal and external carpets of SC detectors.

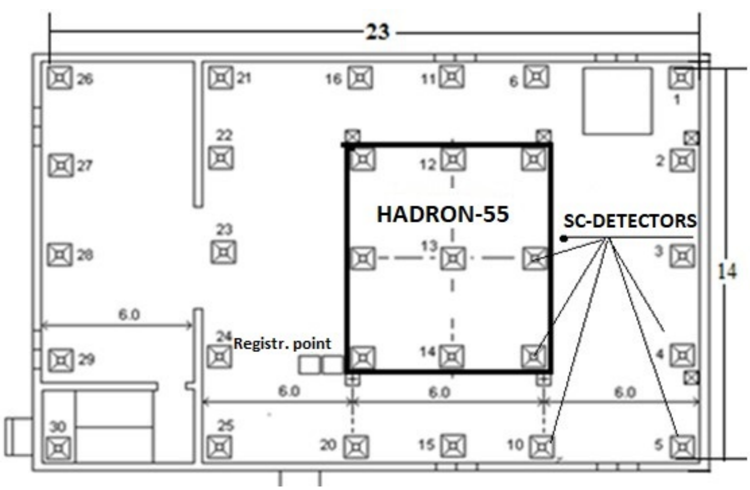

Fig. 1. Scheme of the complex installation HADRON-55. Black square — the ionization calorimeter, small squares with crosshairs — SC detectors.

3. The program algorithm

To process the data, the relation of the tracks in height between the signals received from the ionization cameras are searched. For that purpose, the following algorithm was developed. First, the reference point is the "lower" level of the ionization calorimeter. Two variables "kol" and "rad" are artificially introduced corresponding to the number of the sought correlations and the radius of the sample. The number of the required correlations means the number of values corresponding to one particles flux. The sampling radius means the number of the ionization cameras involved in the correlations search.

According to "kol", a cycle with the registration into new sorted values array of the ionization cameras with their corresponding serial numbers is formed. That needs to search for the most powerful energies registered by the ionization cameras. Then, taking the "rad" variable as a basis, the sample is chosen from the calorimeter row, which is parallel to the sorted one. *I.e.* while sorting 5 rows, the selection is made from 3 rows, further, in the same way from 1 row. In the sample, the search for the maximum value is performed with the registration of the serial number of the ionization cameras in a separate array. The algorithm is based on an assumption that the maximum energy delivered to the ionization camera is the same maximum energy delivered to the higher ionization camera. Further, the obtained correlations are removed from the general array.

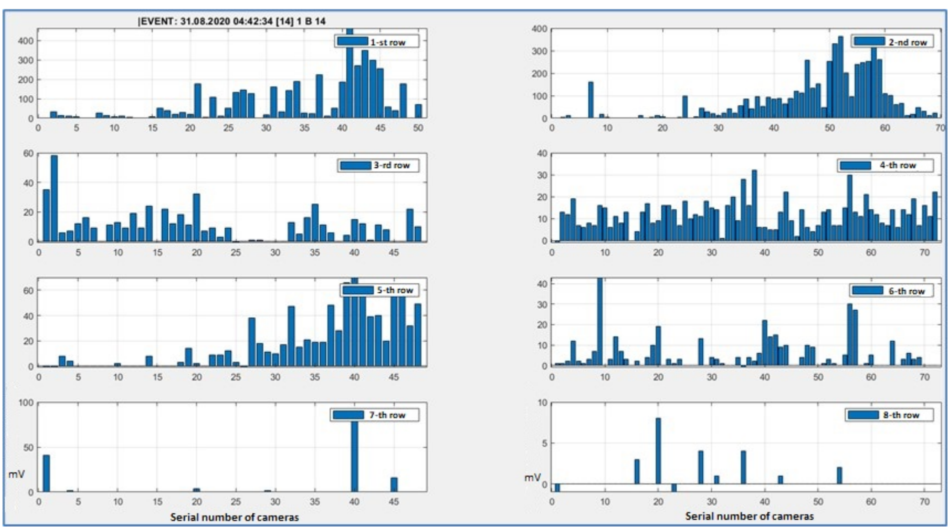

Fig. 2. Energy values obtained from the ionization cameras from event No. 14 of 08/31/2020.

Figure 2 shows the data of event No. 14 from 08/31/2020 with a registration time of 04:42:34. Odd rows 1, 3, 5, 7 on the left and even rows 2, 4, 6, 8 on the right are shown one under the other in two columns. The abscissa is the location of the ionization cameras, the ordinate is the ionization value in mV. For visualization of energy, geometric fluctuations, and correlations in three-dimensional space, the mutually perpendicular rows are combined. For that purpose, the first-row data (the ionization camera serial number and its amplitude) are combined with the second-row data, thereby the interaction coordinate in three-dimensional space is determined.

4. Installation calibration by the EAS energy spectra

The events selection during the registration at the HADRON-55 installation is carried out using a master system or a trigger, which is formed in a special module called the "Master block". The master system has a scheme for summing signals from the ionization cameras and SC detectors, as well as threshold schemes for the formation of a control signal — a trigger. The total signal is directly related to the particles number in the shower and, accordingly, to the power N_e and energy E_0 of the EAS. The master block provides the ability to change the thresholds — 5 fixed threshold levels can be set using a switch. The fixed levels of the master system were calibrated using the EAS energy spectrum measured directly at 3330 m (figure 3). The spectrum relates the appearance intensity "int" with the power N_e of EAS in each range of the powers $N_e(i) - N_e(i+1)$. The intensity is measured in the shower number that fell on 1 m^2/1 h in a solid angle of 1 steradian [sq. M-1 hour-1 ster-1].

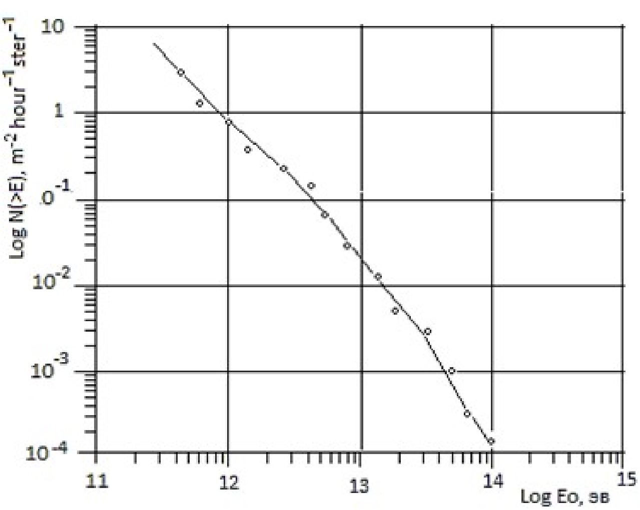

Fig. 3. Energy spectrum of nucleons in cosmic rays at an altitude of 3330 m.

Calibration is performed as follows: set the required threshold on the switch; turn on physical recording and accumulate $N_s = 50$–100 events; calculate the live time ($T_{\rm liv}$) of the session ($T_{\rm liv} = T_2 - T_M$) (T_2 — start time, T_1 — end time, T_M — dead time); calculate the intensity $\mathrm{int} = T_{\rm liv}/(N_s \times S \times T_{\rm liv} \times 2 \times \pi)$; find a point with intensity “int” on the energy spectrum graph and read off the corresponding value of E_0.

5. Conclusion

The HADRON-55 installation is a unique installation that is currently actively used for various tasks in the field of cosmic rays. The described method of processing recorded EASs will help to separate high-energy and low-energy components.

The work was supported by project No. BR10965191 of the Ministry of Education and Science of Kazakhstan Republic.

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