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About one way of organization Unified system for registration of space rays

Today, at the high-mountain scientific station for the study of the physics of cosmic rays, various, independently operating unique experimental installations are used. The ways and methods of combining these installations into a single system are discussed in the article. A single system includes networks of scintillation detectors of the "carpet" type for registration of the electron-photon component, ground and underground monitors for registration of neutron components, calorimeters, Cherenkov detectors, a scintillation spectrometer and a number of other subsystems. The newly created unified system for registering cosmic rays based on the achievements of modern technology and scientific thought will have a high resolution, with a common databank with synchronization in time of operation of separate, independently operating experimental installations. The solution to this problem will help to perform a detailed analysis of the recorded events from a single position, to carry out complex calculations of the spatial distribution, mass composition, and also the energy structure of cosmic rays with a high degree of accuracy. Significant scientific results, obtained in recent years at the Horizon-T experimental installation, are provided. The presented preliminary significant data obtained during the implementation of the project testify to the high information content of the obtained results.

Keywords: cosmic rays, scintillation detector, neutron monitors, fiber optics, local area network, server, extensive air showers, unified database.

Introduction

First of all, it should be emphasized that the physics of cosmic rays belongs to fundamental science. One may ask the question — why does society need fundamental science, which does not bring immediate benefit to mankind, as is sometimes the case with applied research? It should be noted that applied science regularly faces problems that it simply cannot solve itself — neither with the help of accumulated practical experience, nor through the insight of inventors, nor by trial and error. However, they can be solved with the help of fundamental science. Fundamental science is the basis of new high technologies in the long term, technologies understood in the broadest sense [1]. If some small improvements in existing technologies can be made, limiting ourselves to purely applied research, then creating new technologies and with their help solving new problems that regularly face humanity – it is possible only relying on fundamental science [2].

Cosmic ray physics is the physics of elementary particles, one of its facets, which through the development of mathematical formalism is tightly connected with plenty of more "practical" areas of physics, and natural sciences in general. Cosmic rays (CR) are usually understood as fluxes of charged relativistic particles, ranging from protons and helium nuclei to the nuclei of heavier elements up to uranium, born and accelerated to high and extremely high (up to 10^{20} eV) energies outside the Earth [3, 4]. In this case, the contribution of the Sun dominates in the flux of particles with energies up to 10^9 eV, and particles of higher energies are of galactic (and, possibly, at the highest energies, extragalactic) origin. Naturally, protons and nuclei do not exhaust the whole variety of radiation coming to the Earth from outer space. The composition of galactic cosmic rays (GCR) is mainly dominated by protons, the rest of the nuclei account for less than 10% of all inputs. Protons remain the dominant component, at least up to energies of ~ 1TeV, although the fraction of nuclei grows with increasing particle energy.

Certainly, not all physical processes explaining the origin of cosmic rays are understood, and not everything is clear with their effect on the space surrounding the Earth, on biological and technological systems. Every day brings new facts, gives rise to new hypotheses, makes us take a fresh look at seemingly already known physical phenomena [5]. Over the past decades, science has made great strides in understanding the space around us, and scientists are trying to explain and link the seemingly incompatible phenomena into a single chain. The theory of the origin of GCRs, which could be called entirely complete, is currently absent, especially if we bear in mind the origin of GCRs of ultrahigh energies (>10^{15} eV), although over the past 10-15 years in understanding the general nature of the processes in which cosmic rays are emerging and accelerating, a significant progress has been made. A completed theory of the origin of GCRs should explain their main characteristics: the power-law shape of the energy spectrum, the magnitude of the energy density, the mass (chemical) composition of primary CRs including data on the fluxes of antiprotons, electrons, positrons, gamma quanta, the practical constancy of the GCR intensity in time, and their weak anisotropy [6, 7].

The existence of cosmic rays — a stream of high-energy elementary particles coming to Earth from outer space — was established in 1912 by the Austrian physicist V.F. Hess [8, 9]. Later, through the works of subsequent researchers, many new phenomena and patterns were discovered, including the so-called extensive air showers (EAS), the limiting energy spectrum of cosmic rays, which extends up to energy of 10^{20} eV. Particular interest to researchers is the energy range 10^{15}-10^{18} eV, in which a break in the CR energy spectrum was first discovered, and then a number of interesting phenomena incorporating a rather sharp change in the chemical composition of primary cosmic radiation, the appearance of a long-range component, the appearance of delayed particles and showers. The essence of the delay lies in the fact that these particles or the products of their interaction with the atmosphere reach the earth's surface with some delay relative to the front of extensive air showers [10].

Experimental installations, available today in the world for CR registration, are mainly focused on solving individual particular problems. For example, the Yakutsk complex EAS installation, created in the valley of the Lena River, makes it possible to analyze cosmic radiation in terms of energies exceeding 10^{17} eV, to assess its impact on the Earth's atmosphere. The AGASA facility located in Japan was launched almost simultaneously with the facility in Yakutia. The two stations serve similar purposes. Main feature of the AGASA station is considered to be a huge scale – it covers an area of about 100 square kilometers and is a complex of 111 surface detectors and 27 muon detectors. The KASCADE-Grande installation in Karlsruhe is a large ground network of 252 detector stations designed to study extensive air showers. The world's largest Pierre Auger Observatory is located in Argentina, covers an area of 3,000 square kilometers and consists of 1,600 receivers. Its main purpose is to register EASs generated by ultrahigh-energy particles. Nevertheless, despite the complexity and the achieved level of CR registration efficiency, none of the above installations is fully integrated, capable of solving, if not all, then at least the most important sets of tasks and problems facing researchers in the field of physics and cosmic ray astrophysics.

In this regard, this work describes the results achieved to date by combining separate, independently operating basic experimental installations and subsystems of the Physico-Technical Institute (PTI) and the Tien Shan High-Mountain Scientific Station (TSHMSS) into a single integrated system. The structure of this unique complex includes: a flood section, ground and underground neutron monitors; underground muon detectors; neutron detectors; an ionization calorimeter with a gamma-block, where for the first time research is held in the field of cosmic ray astrophysics – gamma astronomy; thrust installation; scintillation spectrometers; EAS radio emission detectors; Cherenkov light detectors; means of registration and analysis of the pulse shape of the EAS leading edge; and a number of other subsystems and means [11]. In addition, the creation of a unified database of experimental results and data extracted by a complex installation helps to take into account all the nuances that arise when accessing various sources of information and their subsequent processing.

Unified integrated system of FTI and TSHVNS

Since the beginning of the sixties of the last century in the vicinity of Almaty city in the mountains of the Zailiiskii Alatau at an altitude of 3340 m above sea level at the experimental site "Cosmostation" by the Physico-Technical Institute of the Ministry of Education and Science of the Republic of Kazakhstan and the Physical Institute named after P.N. Lebedev RAS, joint experiments are being carried out to study the physics of cosmic rays. During this time, fundamental world-class results have been obtained in the study of the CR energy spectrum, measurements of the mass composition, and the search for the anisotropy of primary cosmic rays in various energy ranges. Significantly, more reliable data on CR can be obtained using complex methods of simultaneous registration of charged particles with scintillators, observations of Cherenkov light and radio emission. The advantages of these methods are due to the fact that during the generation of hadron, electron-photon, and muon components, as well as Cherenkov and radio emissions, the atmosphere plays the role of a giant calorimeter, while fluctuations characteristic of the charged component of an EAS are substantially smoothed out. The large scatter of experimental data in the energy range of 10^{16}–10^{19} eV, because its study requires installations with an area of at least a square kilometer at minimum distances between detectors. Due to the low cost of radio emission detectors in contrast to Cherenkov and scintillation detectors, a greater number of such detectors can be placed on the same area and at closer distances from each other, which provides a more detailed study of the spatial and energy structure of EASs. The solution to this problem facilitates to conduct practically round-the-clock measurements, regardless of weather conditions, with a high degree of accuracy, reliability and information content.

Experimental installations of the type "Hadron-55", "Storm installation", "Horizon-T", "Radio emission EAS", "Thunderstorm", "MAS2" (installation for recording earthquakes) and others, which contain a carpet of scintillation detectors, ground and underground neutron monitors, a calorimeter with a gamma block and neutron detectors, Cherenkov light detectors, remote scintillation detectors, a scintillation spectrometer, and a number of other subsystems, are combined into the following items, for which a general network infrastructure scheme has been developed with the ability to connect them to a single dedicated local network (Fig. 1):

- Point "Dormitory", the center of the local network is located here: network and server equipment. Point coordinates: 43.043335N, 76.943078E.
- Point "Boathouse", the center of the storm water installation. Point coordinates: 43.042556N, 76.944330E.
- Point "Physico-Technical Institute", center of the "Hadron-55" installation with a calorimeter, gamma-block and neutron detectors. Point coordinates: 43.044078N, 76.943458E.
- Point "Horizon", registration center of the "Horizon-T" installation. Point coordinates: 43.047177N, 76.945417E.
- Point "Bunker", here are the remote detectors of the "Horizon-T" installation with an autonomous registration system. Point coordinates: 43.049165N, 76.957369E.
- Item "Stone Flower". Remote detectors of the Gorizont-T installation with an autonomous registration system. Point coordinates: 43.050650N, 76.946487E.
- Neutron Super Monitor. Point coordinates: 43.042864N, 76.944314E.
- "Dungeon". Point coordinates: 43.042665N, 76.945063E.

The communication between the subsystems is performed by combining fiber-optic lines into a network, which increased the reliability of communication and the speed of data transmission over the network. The use of a fiber-optic line has increased the resistance of the local network to adverse environmental influences such as precipitation, lightning discharges and static electricity.

Fiber optic lines are built on the basis of Sterlite Aerial Fig-8 Fiber Optic Cable, a self-supporting eight-fiber single-mode cable. The ends of the cable are wound and terminated in optical distribution frames, then they are connected to media converters by means of optical patch cords. The FH-MC100 Series Fiber Optic Media Converter converts 10/100Base-TX connections to 100Base-FX connections and vice versa. The 10/100Base-TX port has 10/100 Mbps auto-negotiation features. The device supports single-mode and multi-mode SC connections. This converter allows for fiber-optic connections at a distance of up to 20 km over two fibers. Media converters are connected to the local network with 10/100Base-TX patch cords.

Figure 1. Fiber optic lines – the basis of the local area network

To improve performance, the local area network was divided into two segments. The first segment with the address range 192.168.11.1–192.168.11.254 (class C network 192.168.11.0/24) includes computers of registration systems, two database servers, a file and Internet server, and a NAS data backup system. The second segment with addresses 192.168.12.1–192.168.12.254 (class C network 192.168.12.0/24) is intended for access from the local network to servers, computers of registration systems and the Internet for all interested users. The network segments are interconnected via the Ubiquiti EdgeRouter ER-X router. Based on Cisco 1760 and Cisco 2620 routers, gateways are used to access the Internet.

In addition, it was decided to include in the local computer network part of the remote subsystems that previously worked autonomously, which would be connected to the local computer network via radio channels. Radio channels for connecting distant points are built on the basis of Ubiquiti AirMAX equipment operating at frequencies of 5.470-5.825 GHz. This band, unlike the 2.4 GHz WiFi band, is less congested and less susceptible to interference. At the central point of the radio network, it is planned to place an Ubiquiti Rocket M5 access point with an Ubiquiti AirMAX Omni 5G10 omnidirectional antenna connected to it. Ubiquiti NanoBeam M5-16 radio bridges will be deployed at remote locations.

Installation of the database server and backup system

When modeling a database server combined with an Internet server, the rack server HUAWEI RH2285V2 is used as a layout. The server includes two Intel Xeon E5-2400 4-core CPUs, 16GB RAM DDR3, two 1TB hard disks combined into a mirrored disk array RAID 1. The network equipment is represented by two 10/100/1000 Mbps Ethernet interfaces. The server runs under Scientific Linux operating system version 7.8. To work with databases, a free object-relational database management system PostgreSQL version 11.9 is deployed on the server. NTP daemon version 4 is running on the server, providing synchronization with world time with an accuracy of no worse than 10 ms (1/100 s) when working via the Internet, and up to 0.2 ms (1/5000 s) inside local networks.

Application package

A package of application programs for working from a local network is programs that use the developed libraries, form queries to databases, transfer the requested records to the program content and process them in accordance with the specified criteria. The processed data will be presented in text or graphic form. Using the Linux operating system, programming languages C, C ++, Python, Java, Java script, programming interfaces and modules have been developed and debugged, allowing to transfer database records into program content.

2. Significant research results at the Horizon-T installation

Horizon-T installation [12] registers the fluxes of charged particles of EAS with energies above 1016 eV and with nanosecond precision. It is designed to study the space-time structure of shower disks. Installation observation level is at 3340 m above sea level (see Figure 2).

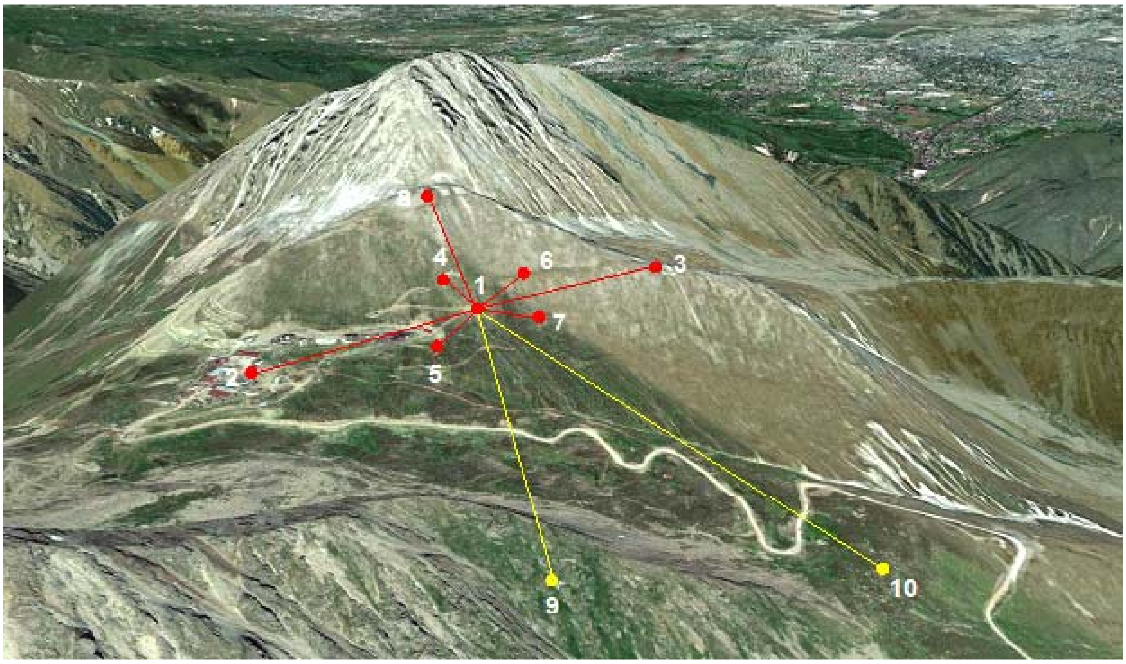


Figure 2. Geometry of the location of registration points of the Horizon-T installation

The space-time characteristics of the fluxes of charged particles of EAS, which were obtained at the Horizon-T installation, are compared with the space-time characteristics of the fluxes of charged particles of electron-nuclear showers from protons, which were obtained using the CORSIKA model package [13].

The composition of particles that reached the Earth's surface in electron-nuclear showers from primary protons with an energy of $2x10^{17}$ eV, which were obtained by drawing for the CORSIKA model package, was considered. Gamma quanta, neutrinos, electrons, positrons and muons dominate in these particles.

In the present experiment, charged particles were considered when the difference between an electron and a positron is not significant. “Electrons” and “positrons” were considered as “electrons”. In an electron-nuclear shower with energy $2{\cdot}10^{17}$eV, from the vertical direction to the observation level, on average, about 10^{8}charged particles, in a shower with an energy of $2{\cdot}10^{18}$eVon average pass about 10^{9}particles.

Among charged particles that come to the observation level from directions close to the vertical (up to zenith angles of 30°), the fraction of electrons is close to 99%, the fraction of muons is about 1%. By increasing zenith angles, the electron flux density decreases, and the muon flux density increases, and in the EAS from the zenith directions more than 70° the muon flux density exceeds the electron flux.

Conducted drawings of electron-nuclear showers using the CORSIKA model package illustrated the following:

1. With an increase in the distance to the shower axis, the flux density of charged shower particles at the observation level decreases rapidly.

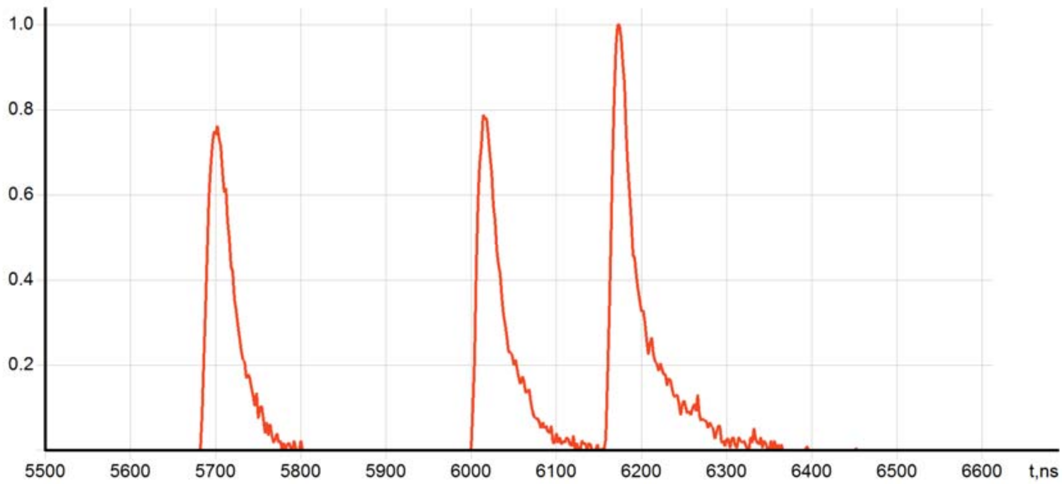
2. Only one storm disk arrives at an altitude of 3340 m above sea level, unaccompanied by delayed particles. Therefore, when streams of charged particles of a shower pass through the detector, a pulse with only one maximum is formed.

3. The duration of the pulse in the SC detector from the passage of charged particles of the shower increases rapidly with increasing distance to the axis of the shower.

Below is an analysis of the experimental material obtained at the Horizon-T installation from March 21 to May 12 2018, when over 1137 hours, 15725 events were recorded with an intensity of 13.8 events / hour and a detection threshold of $2 \cdot 10^{16}$eV.

More than 500 showers were found in this experimental material, in which delayed particles are observed. In showers with energies less than10^{17}eV, recorded with the Horizon-T installation, any pulses had only one maximum. All showers with delayed particles have energies above 10^{17}eV. The recorded intensity of showers with delayed particles does not contradict the luminosity of the installation.

The term delayed particles implicitly implies that one group of particles crosses the observation level as a part of the shower disk, while the other group of particles is delayed from the main shower disk. Experimental data obtained at the Horizon-T installation indicate that delayed EAS particles cross the observation level, forming two, three, or more pulses in the detectors along with the first pulse. An example of three pulses recorded in a shower with energies above $5 \cdot 10^{17}$eV, which came at a zenith angle of 30° from the southwest direction, is illustrated in Figure 3.



Note. The delay time of the second pulse from the first pulse is t_{12} = 318 ns, the third pulse from the second pulse is t_{13}= 465 ns.

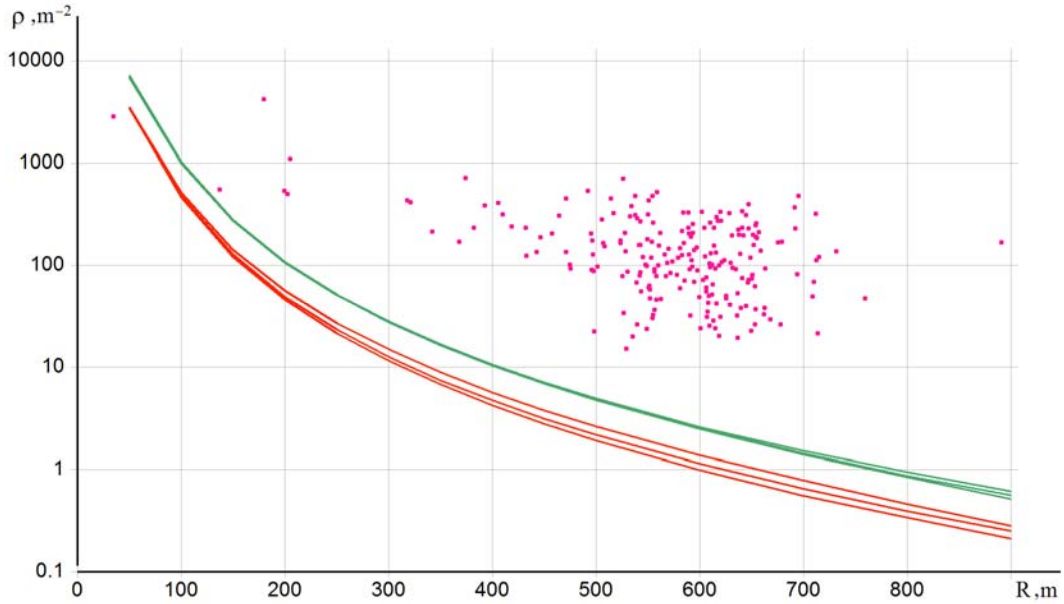
Figure 3. Three pulses recorded in a shower with an energy higher than $5 \cdot 10^{17}$eV

The first pulse has a duration of τ_1=35 ns and is generated by the passage of 316 particles, the second pulse has a duration of τ_2= 32 ns and is generated by the passage of 327 particles, the third pulse has a duration of τ_2= 28 ns and is generated by the passage of 363 particles. Obviously, in this shower, the detector was crossed by particles of three shower disks. A disk that formed the first impulse came earlier than the others, but it does not follow from this that the disk is the main one. The term "delayed particles" simply means that the origin of the time scale is associated with the first disk. These three pulses, generated in the detector by particles of one shower, were considered as a single geometrical object, with three maxima (modes) and were called a trimodal pulse. The pulses with several peaks recorded in the detector were called multimodal pulses, respectively, showers in which multimodal pulses were recorded – multimodal showers.

Experimental data on multimodal showers obtained at the Horizon-T installation indicate that particles in such showers cross the observation level as part of several shower disks, each of which generates its own pulse in the detector of the facility.

In electron-nuclear showers with energies up to 10^{18}eV played out using the CORSIKA package of models, charged particles at any distance from the shower axis formed only one pulse. The modern physical concepts of electron-nuclear showers, which are implemented in the CORSIKA package of models, do not give delayed particles in EASs.

Figure 4 demonstrates the field of points with coordinates (R, ρ) for bimodal pulses recorded in the SC detector at point 9 in 217 showers. The curves are the functions of the spatial distribution ρ(R) in electron-nuclear showers, obtained in a raffle applying the CORSIKA package of models.



Note. The curves are the functions ρ(R) of the spatial distribution of charged particles of six electron-nuclear showers, which were obtained by drawing according to the CORSIKA model. Red curves – three showers with an energy of $5{\cdot}10^{17}$eV, green curves – three showers with an energy of 10^{18} eV.

Figure 4. Field of distribution of points with coordinates (R, ρ) in 217 showers recorded at the Horizon-T installation

The bimodal pulses recorded in point 9 are caused in the SC detector by charged particles, the flux densities of which are much higher than the flux densities of electron-nuclear showers with energies of 10^{18}eV at distances of 600 m from the shower axis, obtained using the CORSIKA model package. The distribution of points (R, ρ) in Fig. 4 shows that at R > 400 m, the experimental SDF does not change with increasing R. While the SDF of charged particles in electron-nuclear showers decreases several times.

Figure 4 designates that in electron-nuclear showers with energies of 10^{18} eVthe flux density of charged particles at a distance of 400 m from the shower axis is ρ_{400}=10.0 m^{-2}. Taking the flux density of charged particles in an electron-nuclear shower proportional to the shower energy, it can be estimated that a 10 times higher flux density ρ_{400} = 100 m^{-2} will appear in electron-nuclear showers at energies of 10^{19} eV. Accordingly, the flux density ρ_{400} = 300 m^{-2} can be recorded in electron-nuclear showers at energies of $3{\cdot}10^{19}$ eV.

The performed estimates of the luminosity of the Horizon-T installation showed that in 1137 hours it is capable of registering, on average, 1 electron-nuclear shower with an energy of 10^{19}eV and above. Registration of 108 electron-nuclear showers with energies of 10^{19}eV and above will require on average more than one hundred thousand hours. Registration of 27 electron-nuclear showers with energies of $3{\cdot}10^{19}$eV and above will require substantially more than one hundred thousand hours. Hence, it follows that bimodal impulses recorded at distances R=(400÷750) m cannot be generated by particles of electron-nuclear showers.

Results and Discussion

1. In EAS with energies above 10^{17}eV, the Horizon-T installation has recorded delayed particles that form a system of pulses in the detectors. The system of several pulses recorded in the detector is called a multimodal pulse – a pulse with several modes. EASs, in which multimodal impulses were recorded, are called multimodal EASs.

2. Analysis of electron-nuclear showers with energies from 10^{17}eV to 10^{18}eV, obtained applying the CORSIKA package of models, showed that delayed particles do not appear in electron-nuclear showers and, accordingly, only one pulse with one maximum (mode) can be recorded in the detectors. Therefore, it follows that multimodal EASs are not electron-nuclear showers.

3. The quantitative characteristics of bimodal impulses were studied. The behavior of these characteristics showed that in showers, which are called "EAS with delayed particles", a system of several shower disks comes to the observation level. When the axis of one of these shower disks passes near the detector, a pulse is formed in the detector, the duration of which is an order of magnitude shorter, and the flux density is an order of magnitude greater than expected in electron-nuclear showers. This confirms that multimodal EASs are not electron-nuclear showers.

Conclusions

Combining all experimental installations into a single registration system with a common data bank makes it possible to perform a detailed analysis of events, complex calculations of the spatial and energy structure of EASs with a high degree of accuracy and reliability of the obtained results. A network infrastructure and a central server have been created to organize a single base of the entire system with the connection of individual experimental installations to a single dedicated local network. The organization of time synchronization of the operation of individual experimental installations with each other is ensured. The software support has been developed and debugged, which ensures the normal functioning of the entire infrastructure and uninterrupted client access to the database of the combined system.

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Ғарыш сәулесін тіркеуге арналған бірегей жүйені құрудың бір тәсілі туралы

Бүгінгі күні ғарыш сәулесінің физикасын зерттеуге арналған биіктаулы ғылыми станцияда әрқайсысы дербес жұмыс істейтін, баламасы жоқ көптеген дара қондырғылар пайдаланылуда. Мақалада құрамында ғарыш сәулесінің электрон-фотон құраушысын тіркеуге арналған сцинтилляциялық детекторлармен құрылған «кілем», сәуленің нейтрондық құраушыларын тіркеуге арналған жерасты және жерүсті мониторлары, калориметрлер, черенков сәулесінің тіркеуіштері, сцинтилляциялық спектрометрлер, жер сілкінісін қадағалауға арналған қондырғы мен көптеген қосалқы құрылымдарды біріккен бірегей жүйеге айналдырудың әдістері мен техникалық шешімі қарастырылған. Қазіргі заман технологиясының алдыңғы қатарлы жетістіктері мен озық ғылыми пікірлерге сүйену нәтижесінде құрылған ғарыш сәулесін тіркеуге арналған бірегей жүйе шешуші қабілеті жоғары, арнайы дайындалған бағытты бағдарламалар арқылы басқарылатын ортақ мағлұматтар қоры бар, тәуелсіз жұмыс істейтін дербес эксперименталдық маңызды қондырғыларды синхронды түрде басқаруға арналған жүйелік құрылымдармен жабдықталған қондырғыны жинақтап құру принциптері баяндалады. Маңызы ерекше және айрықша күрделі бұл проблеманың іс жүзінде орындалуы нәтижесінде тіркелген ғарыш сәулесі туралы мағлұматтарды мейлінше мұқият талдауға, олардың кеңістікте таралуы, массалық құрамы және энергетикалық құрылымы туралы есептеулерді жоғары дәлдікпен орындау арқылы ақпараттарды бір позициядан суреттеуге мүмкіндік туады. «Горизонт-Т» эксперименталдық қондырғысынан соңғы жылдары алынған алғашқы ғылыми нәтижелер берілген. Жобаны орындау барысында алынған алғашқы деректер қол жеткен нәтижелердің мағлұматтық құндылығының жоғары екендігін дәлелдейді.

Кілт сөздер: ғарыш сәулелері, сцинтилляция детекторы, нейтрон мониторы, талшықты оптика, жергілікті желі, сервер, ауқымды атмосфералық нөсер, бірегей мағлұматтар қоры.

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Об одном способе организации единой системы регистрации космических лучей

В настоящее время на высокогорной научной станции для исследования физики космических лучей используются различные, независимо действующие уникальные экспериментальные установки. В статье рассмотрены пути и методы объединения этих установок в единую систему, включающую в себя сети сцинтилляционных детекторов типа «ковер» для регистрации электронно-фотонной компоненты, мониторы наземного и подземного базирования для регистрации нейтронных составляющих, калориметры, черенковские детекторы, сцинтилляционный спектрометр и еще ряд подсистем. Вновь созданная единая система регистрации космических лучей на основе достижений современной технологии и научной мысли будет обладать высокой разрешающей способностью, с общим банком данных с обеспечением синхронизации по времени работы отдельных, независимо действующих экспериментальных установок. Решение этой проблемы позволит выполнение детального анализа регистрируемых событий с единой позиции, проведение сложных расчетов пространственного распределения, массового состава, а также энергетической структуры космических лучей с высокой степенью точности. Приведены значимые научные результаты, полученные в последние годы на экспериментальной установке «Горизонт-Т». Представленные предварительные значимые данные в проекте свидетельствуют о высокой информативности полученных результатов.

Ключевые слова: космические лучи, сцинтилляционный детектор, нейтронные мониторы, волоконная оптика, локальная сеть, сервер, широкие атмосферные ливни, единая база данных.

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