Autumn school "Interactions of hadrons at super-accelerator energies"

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The tradition of the autumn schools on the physics of the interaction of hadrons at super-accelerator energies, organized regularly every two years by the Physics Institute, Erevan (ErFI), was not broken in 1990 although the economic difficulties of the Republic, numerous strong earthquakes in 1988 and a blockade did raise doubts with regard to the ability to conduct the school. To the honor of its organizers it must be stated that they did their utmost in order that these difficulties would have minimal effect on the operation of the school. It was held in Nor-Amberd during the last week of September.

The school brought together more than 50 lecturers and auditors. For the first time foreign scientists participated in the work of the school. Seven physicists from 5 countries (Bulgaria, Ireland, Poland, France and Japan) responded to the invitation. Their participation enlivened the work of the school, increased interest in the materials presented at it and was very definitely worthwhile.

Opening the school, É. A. Mamidzhanyan, Chairman of the Organization Committee, and A. Ts. Amatuni, Director of ErFI, recalled that these schools began in the 1980s as a direct continuation of the schools on the physics of elementary particles, which had been conducted in Nor-Amberd in the 1960s under the direction of A. I. Alikhanyan. On the other hand, they are successors of the working conferences, conducted regularly during the 1980s in connection with construction at the Aragats mountain station of the ANI complex for studying cosmic rays of ultrahigh energies, built jointly by ErFI and FIAN SSSR [P. N. Lebedev Physics Institute, Academy of Sciences of the USSR, Moscow]. The difficulties, experienced by the Republic, also exerted a delaying influence on the construction of ANI. However, despite all impediments, efforts to complete it have continued. During the two years since the last school the "ANI prototype" apparatus was started up, resulting in considerable advancement of the construction of the 1600 m^2-area ionization calorimeter. The ground-level scintillation detectors, which together with similar detectors in the underground laboratory should comprise the "Gamma" apparatus for recording the electron and muon components of extensive air showers (EAS). The assembly of the windings of the giant underground magnet—the principal part of the magnetic spectrometer for investigating high-energy muons in the extensive air shower cores—has begun. The participants of the school could see all this during an excursion to the Aragats mountain station. The mirror gamma-ray telescope for investigating discrete sources of gamma radiation in the TeV energy region has been mounted at the Nor-Amberd station and is ready for operation.

Although the problem of the interaction of hadrons at super-accelerator energies was put into the name of the school, the actual subject matter of the review lectures and original reports presented at the school was much broader. It encompassed primary cosmic radiation, gamma-ray astronomy questions, new projects and facilities, methods of detecting radiation and processing experimental data, and questions of theory. A discussion of new phenomena observed in cosmic rays occupied a majority of the time, as had been planned at the previous school.

As already reported earlier in papers and publications devoted to the ANI project, the interaction of hadrons at this facility will be investigated by studying the macro- and microstructure of extensive air shower cores in the 10^3–10^6 TeV energy region. The shower detectors of the "Gamma" facility, the underground magnetic spectrometer and the ionization calorimeter will give information on the macrostructure of the cores. The microstructure of these cores will be visible in the x-ray films placed inside the ionization calorimeter. Thus, active electronic methods of recording EAS and passive detectors, such as the x-ray films, will be combined in the ANI complex. To work out the methods of such a combination two experimental facilities having a 7–10 times smaller area were built. The already-mentioned ANI prototype, in which the complicated technique of the moving x-ray films must be worked out, has only just begun to yield information. The other simpler facility with stationary x-ray films, which has been given the name of "Hadron", has been operating since 1985 at the Tien Shan station of FIAN and has already accumulated considerable experimental data.

A report by S. B. Shaulov (FIAN) was devoted to the results of an analysis of this material. The report included energy spectra of the electrons and photons in wide air shower cores of different energy. Considerable softening of these spectra is shown in the transition to showers with $N_e > 10^7$ total number of particles; this means a drastic breakdown of scaling in the fragmentation region of secondary hadrons generated in inelastic collisions with the nuclei of air atoms in the 5×10^{15}–2×10^{16} eV energy interval.

S. I. Nikol'skiĭ (FIAN) made considerable use of this result in his report. The report was a review devoted to a consideration of the nuclear physics problems facing the ANI complex at the present stage of development of high-energy physics. A number of effects observed earlier in cosmic rays suggest that the breakdown of scaling in the 10^{16} eV region is a reflection of the unique features of hadron-nuclear interactions, appearing even at energies of the order of 2×10^{13} eV. These features are manifested as additional energy losses by nucleons and are related to the presence of the space-time scale of the hadronization of quarks. In order to determine to what secondary components the excess energy, lost by the nucleons, is transferred it is advisable to place scintillation detectors beneath the ANI ionization calorimeter to investigate the particles carrying energy to the bottom of the hadron cascade, and to determine the time delay of their appearance.

Supporting the basic ideas contained in Nikol'skiĭ's report, A. Osawa (Japan) presented evidence that the breakdown of scaling in nucleon-nucleon collisions also shows itself at energies below 10^{16} eV. Observation of the gamma-hadron families with the necessary "centaur" properties in x-ray emulsion chambers, exposed by a Japanese-Brazilian collaboration at Chacaltaya in Bolivia, forces one to think that the additional energy lost by the nucleons is transferred to new heavy particles, which then decay into baryons.

Osawa told about a new project of the "Omega" Japanese-Brazilian collaboration, planned for investigating families with unusual properties and primary cosmic radiation at energies above 10^{16} eV. In its plan it is identical to ANI, i.e., it is a facility combining a 900 m^2 area x-ray emulsion chamber with electronic detectors: a detector of the energy of the electromagnetic component on the basis of scintillating fibers and conventional plastic scintillation detectors for the identification and determination of EAS parameters. The facility will be located at Chacaltaya.

The talk by D. M. Kotlyarevskiĭ (IF AN Grusii) [Institute of Physics, Georgian Academy of Sciences] was devoted to the characteristics of hadron-nuclear collisions from the results of studies at the Tskhra-Tskharo mountain station. Data were presented on the partial and total inelasticity coefficients in the interactions of the hadrons of cosmic rays (75–80% N, 20–25% π) with the atomic nuclei of CH_2, Al, Cu and Pb in the 0.22–1.5 TeV interval of energies. Experimental data on hadron-nucleon, hadron-nucleus and nucleus-nucleus collisions, obtained on accelerators, were also presented and analyzed. It was shown that for the inelasticity coefficients K_{ch}, K_γ, K_{tot} there is essentially no dependence on the initial energy, and an A-dependence of the type $\sim A^{0.10 \pm 0.02}$ is observed, and there is a strong dependence on the nature of the incident particles; for AA-interactions: K_π-is observed in the front (f) and back (b) hemispheres, with $(K_\pi -)_f$ depending only slightly and $(K_\pi -)_b$ increasing with an increase in the atomic number of the target.

I. I. Roĭzen (FIAN) reported on questions of investigating deep-inelastic processes and rigid scattering on colliders of the future in connection with the problem of the density of partons at small values of x. Present information about the structure functions of nucleons, obtained from deep-inelastic scattering, is for the region $x > 10^{-2}$, where the partons can be assumed to be independent. It is expected from theory that for $x < 10^{-3}$ the density of partons should increase so much that they begin to interact with each other and cease to be independent. The behavior of the scattering cross section, caused by the interaction of such soft partons, should be altered. Fairly high energies are required in order to penetrate into the region of small x and large transferred momenta $Q^2 > 10\ (\mathrm{GeV}/c)^2$. It was pointed out in the report that quantitative studies of the structure functions of nucleons in the $x \approx 10^{-4}$ region can be carried out only on future colliders—the electron-positron HERA and the proton-proton LHC and SSC.

Several lectures at the school were devoted to primary cosmic radiation. V. Ya. Shestoparov (NIIYaF MGU) [Scientific Research Institute of Nuclear Physics, Moscow State University] presented, on behalf of his group of coworkers, an experimental spectrum of primary protons in the 2–100 TeV energy region, measured on a satellite by means of the "Sokol" equipment. Unlike previous reports at this school and publications, the authors took into consideration a number of new, "finer" effects which, however, did not lead to a significant change in the results. The differential energy spectrum of protons at energies above 5 TeV has the exponent $\gamma + 1 = 2.82 \pm 0.21$. If one takes into consideration that the energy spectrum of all primary cosmic ray particles in the 2-100 TeV interval has a flatter character than the spectrum of protons ($\gamma + 1 = 2.65$–2.70), then it follows from this difference that the fraction of protons in the primary cosmic rays has a tendency to decrease slowly. However, this decrease does not exhibit such an extreme character as was obtained on the "Proton" satellites and is confirmed on the basis of an independent analysis of the "Sokol" data carried out by N. L. Grigorov. Besides this discrepancy the question remains whether this tendency for the fraction of protons to decrease is retained at higher energies of $\sim 10^3$ TeV or whether the nuclear composition of the primary cosmic rays is gradually stabilized.

As of the present time there are no direct experimental data on the composition at energies of several PeV. An indirect analysis of the composition in the region of the "knee" (2–3 PeV) was made in the joint Soviet-French work of FIAN and the University of Bordeaux. This work was reported by the French physicist J. Procureur (Bordeaux). The experimental results on the fluctuations of the muon and electron components of EAS, obtained at Tien Shan, were analyzed anew in this work. The analysis was performed using a more realistic independent-nucleon model for AA-collisions. In accordance with the experimental data this model leads to a much higher value of the fluctuations than the superposition model, which was used in the earlier analysis of this same material. As a consequence, the ambiguity of the analysis results is increased. However, despite the increased errors in the determination of the contribution of different nuclei, one can state that the mass composition of primary cosmic rays is apparently heavier than at lower energies. At an energy of 2–3 PeV it is characterized by the following values: $17 \pm 4\%$ P, $15 \pm 7\%$ He, $16 \pm 10\%$ M, $20 \pm 8\%$ H, $32 \pm 8\%$ VH. On the basis of this result one can assume that the decrease in the proton fraction and, conversely, the increase in the fraction of nuclei of the VH group in the primary cosmic rays continues to the vicinity of the knee in the spectrum.

The key here, of course, lies in future direct measurements, which are planned both here in the USSR as well as abroad. The same group from NIIYaF MGU, which worked with the "Sokol" equipment, has presented a plan for a facility to continue investigations of the energy spectra of various high-energy nuclei from protons to iron and to advance these studies to an energy of 1 PeV on the nucleus (D. I. Podorozhnyĭ). In the proposed AYaKS equipment a further development of the basic principles used in the "Sokol" instrument is used. For the same overall geometrical parameters and weight as in the "Sokol" the exposure factor for the new equipment will be increased by more than a factor of 100.

Preliminary results of theoretical work begun at ErFI to calculate the evolution of the nuclear composition of cosmic rays in a photon field of sources and interstellar medium were reported by A. S. Ambartsumyan.

Gamma-ray astronomy occupied an important place among the problems discussed just as at the previous school. This is due to the undiminished interest in this area. A paper was read at the school in which a result that is still unique was reported by M. Cowley (Ireland). He talked about investigations of the Crab nebula by means of the 10-meter reflector at the Whipple Observatory in the USA. A camera of 109 photomultipliers was placed at the focus of this telescope, which makes it possible to obtain an image of a spot from the flash of Čerenkov light caused by the passage of EAS through the atmosphere. Observations of the Crab nebula were conducted for 30 hours between November 1988 and March 1989. It was known from earlier reports and publications that the material from $\sim 500{,}000$ events gathered during this time both in the direction of the Crab nebula and also outside this direction made it possible to achieve a signal $\sim 5\sigma$ above the background. Using a selection of events from a characteristic of the image such as the azimuthal width made it possible to reduce the background and obtain a signal $\sim 19\sigma$ above it, which is already an outstanding result. However, the participants in the experiment did not stop there. In cooperation with Soviet physicists at ErFI and the State University of Altai (AGU) they used an even more complicated technique of analysis, employing correlations between different parameters of the image (width, azimuthal width and length) and improved the significance of the effect to $\sim 27\sigma$.

The flux of gamma rays from Crab obtained in this work: $(7.0 \pm 0.4) \times 10^{-11}$ cm^{-2}s^{-1} at energies above 0.4 TeV makes it possible to use it for the calibration of other instruments. The slope of the integrated spectrum is characterized by the exponent $\gamma = 1.4 \pm 0.1$. No variations are observed in this flux on a time scale from 0.5 h to 1 month. Also, no pulsating component of the radiation is observed and the authors estimate that the flux of gamma rays from pulsars with a period of 33 msec does not exceed 10% of the total flux from the Crab nebula.

Cowley also reported on studies of other discrete sources of gamma radiation although with fewer successes. Observations totaling 124 hours of the 4UO115 + 63 pulsar during 1985–1988 did not result in his finding either a direct flux nor its second harmonic after employing a phase analysis with the period of the pulsar. The upper limit of the flux from this source is estimated to be 1×10^{-11} cm^{-2}s^{-1} at energies above 0.7 TeV.

The same negative result was obtained after 6 years of observations (1984–1989, 445 hours) of the Hercules X-1 binary system. No gamma radiation from this source could be detected either in a direct flux nor after a phase analysis nor as a result of an analysis of the images. There was, however, a brief period—May to July 1986—when three observatories—Whipple, Haleakala in Hawaii and Los Alamos—independently observed radiation from Hercules X-1. A strange thing about this radiation was the fact that it had a blue shift of 0.16% compared with the pulsar period of 1.24 sec. Moreover, it apparently was not of electromagnetic origin since, first of all, an analysis of the images at the Whipple Observatory did not improve the signal/background ratio and, second, the fraction of muons in EAS from this source, observed at Los Alamos, was by no means less than in normal extensive air showers of nuclear origin.

No radiation was found either from the 1E2259 + 586 binary x-ray source. Thirteen hours of observations in the period 1985–1988 made it possible to determine only the upper limit of flux: $I < 2.4 \times 10^{-11}$ cm^{-2}s^{-1}, which is a factor of 8 smaller than the result of the Durham group, obtained at the same time.

The review by F. A. Agaronyan (ErFI) was devoted to neutral radiation of very high (> 1 TeV), ultrahigh (> 1 PeV), and extremely high (> 1 EeV) energies from compact astrophysical objects. The study of compact sources in the very near future will be of high priority because of the hardness of their radiation spectra, as a result of which it will be possible to detect them. Neutral radiation includes gamma rays, neutrinos and neutrons. The mechanism for the formation of the spectra of gamma rays, neutrinos and neutrons in sources, the suppression of neutrino spectra because of cascading of hadrons, the absorption and cascading of gamma rays, their interaction with magnetic fields, and the transfer of energy from accreting plasma by relativistic neutrons were examined. The γ/p ratio in the blackbody cutoff region of cosmic ray spectra ($E > 5 \times 10^{19}$ eV) was discussed and it was indicated that at a sufficiently low energy density of the radio background and magnetic fields in intergalactic space the contribution of gamma rays in the EAS flux can dominate. Then the divergence of data on wide air showers of extremely high energies can be explained by the different sensitivity of experimental apparatus to the recording of electromagnetic showers. It was also pointed out that because of interaction with the geomagnetic field a gamma ray of extremely high energy cascades until it arrives in the atmosphere, and the electromagnetic shower from it can be similar to a proton shower since the influence of the Landau–Pomeranchuk–Migdal effect will be reduced. Moreover, the number of muons with an energy of the order of several hundred MeV in the electromagnetic shower can be comparable with the total number of such muons in the shower of a primary proton or even exceed it.

Details of a calculation of the features of the development of electromagnetic showers of extremely high energies, making them similar to conventional extensive air showers of nuclear origin, were also presented in a report by V. A. Saakyan (ErFI).

Ĭ. N. Stamenov (Bulgaria) reported on the results of a search for and study of compact sources on the basis of material accumulated by the Tien Shan EAS facility in 1974–1982. The search was conducted at energies higher than 150 TeV with a cell having a 15° angular aperture. Significant fluxes at the $\sim 3\sigma$ level are obtained only through the use of phase analysis for three sources: 4UO115 + 63 ($I = (4.4 \pm 1.5) \times 10^{-14}$ cm^{-2}s^{-1}, $\phi = 0.5$–0.6), V1727Cyg ($I = (4.2 \pm 1.5) \times 10^{-14}$ cm^{-2}s^{-1}, $\phi = 0.8$–0.9 and $(5.2 \pm 2.0) \times 10^{-14}$ cm^{-2}s^{-1}, $\phi = 0.4$–0.5), and β Per ($I = (5.7 \pm 2.1) \times 10^{-14}$ cm^{-2}s^{-1}, $\phi = 0.3$–0.4). Long-term variations of the intensity of the Cygnus X-3 source have been observed: a peak with a magnitude of 4σ has been obtained at a phase of $\phi = 0.04$–0.14 for a period $P = 321 \pm 3$ days. The existence of an orbital periodicity has been established for the Hercules X-1 ($I = (4.4 \pm 2.0) \times 10^{-13}$ cm^{-2}s^{-1}, $P = 1.7$ days, $\phi = 0.86$–0.96) and Cygnus X-1 ($I = (5.8 \pm 2.1) \times 10^{-13}$ cm^{-2}s^{-1}, $P = 5.6$ days, $\phi = 0.5$–0.8). This periodicity is also preserved for a sampling of EAS depleted of muons, with $N_\mu / \langle N_\mu \rangle < 0.3$. A correlation apparently exists between the type of source and the width of the peak on the phase diagram: massive binary systems like Cygnus X-1 and 4UO115 + 63 are characterized by the presence of a wide peak, while binary systems with a small mass such as Cygnus X-3, V1727Cyg, and Hercules X-1 are characterized by relatively narrow peaks.

V. S. Aseĭkin (FIAN) reported on the negative results of a search for radiation from the Crab nebula on the Gamma telescope system mounted at Tien Shan. The search was conducted within an 8°×8° solid angle with a resolution of 0.8° during 34 hours in 1989. The work was methodical in character, the recording thresholds exceeded the thresholds of the Whipple telescope by more than an order of magnitude, and no images were analyzed. Therefore, it may be that thus far the only success has been that of setting upper limits on the fluxes: $<7.4\times10^{-11}$ cm^{-2}s^{-1} above 7 TeV and $<2.4\times10^{-12}$ cm^{-2}s^{-1} above 20 TeV.

The indication of an excess of hadron groups in the direction of the Cygnus X-3 source was also checked at Tien Shan. This indication was obtained from data of the PION facility at Aragats, and it had been mentioned at the previous school. The Tien Shan data were obtained during a different time interval—1978–1982 vs 1984–1985—at ErFI although over a longer period—12,000 hours—and by means of a factor of four larger calorimeter. E. I. Tukish (FIAN) reported on these matters. No excess of hadron groups was found. Although, as already pointed out, the observation conditions and the criteria for sampling the groups were different, the negative result of the search at Tien Shan may indicate, in agreement with the results of other studies, the sporadic character of the radiation of Cygnus X-3 or it may cast doubt on the very existence of "hadron" astronomy.

Several reports at the school were devoted to new plans, detectors, and methods for analyzing and processing experimental data. A review paper by B. I. Luchkov (MIFI) [Engineering-Physics Institute, Moscow] was devoted to a recording of gamma rays in the 1 GeV–1 TeV energy interval. This interval is the "white spot" of gamma-ray astronomy. No universal method has yet been found that combines large area (>1 m^2) and high detector angular resolution ($<1°$) with simplicity and reliability. Recently, however, a number of plans have appeared based both on traditional methods and also on new ideas. Among the traditional detectors the speaker pointed out three: the "Gamma-400" project (USSR, FIAN-MIFI), SSCT (Japan) and Wizard (USA). The solid-state Čerenkov counter developed at CERN, making it possible to construct a ring image from a shower caused by a gamma ray, is based on new ideas. By measuring the ellipticity of this ring one can determine the entry angle of the gamma quantum with an accuracy of the order of a few mrad.

The first tests of the "Vega" detector (Japan) for the recording of gamma rays with $E_\gamma > 40$ GeV from a measurement of secondary electrons at aircraft altitudes has undergone its first tests. It includes a scintillation hodoscope, hadron counter and calorimeter. The method is based on looking for excesses of electrons with energies above 1 GeV in the direction of the astrophysical objects being studied. The Vega combines a large geometrical factor ($S\Omega = 1.4$ m^{2}sr) with good angular accuracy ($\delta\theta = 1.2 \pm 0.1°$) and proton rejection (95%). An obvious drawback of the method is the enormous background of cosmic rays at aircraft altitudes of 10 km, which was demonstrated during the first flight.

A fundamentally new method for a narrow-angle telescope ($\delta\theta = 1$ mrad) is based on using a mosaic of oriented silicon single crystals as a converter of gamma rays and for measuring the shower emerging from the crystal. The advantage of this detector is the complete absence of a hadron background. Various modifications of such telescopes for operation in satellites have been suggested by the FIAN-MIFI group and also by the Novosibirsk IYaF [Institute of Nuclear Physics] and Danish physicists. Their main goal is to determine more precisely the coordinates of discrete sources already known, such as from the COS-B catalog.

R. G. Mirzoyan reported on the joint effort of ErFI with the HEGRA collaboration to build a comprehensive astronomical facility on the Canary Islands. The principal part of the facility—a shower facility with the addition of a large number of muon detectors—is being built by several foreign universities. The contribution of ErFI consists of building five Cerenkov telescopes of the type which can already be seen in Nor-Amberd. The speaker described the characteristics of this telescope: 18 mirrors 0.6 m in diameter, angular resolution of 0.4°, with the chamber consisting of 37 FÉU-130 photomultipliers. An analysis of the images of a Čerenkov flash will make it possible to suppress the proton background by a factor of 50 with a factor of 1/2 loss of the effect. The threshold energy for a shower from a gamma ray is ~ 1 TeV. The planned distance between telescopes at the HEGRA facility is ~ 100 m. Such a system is capable after 50 hours of observations to detect a minimum gamma quantum flux of 10^{-12} cm^{-2}s^{-1}. The work programs of the shower and Čerenkov parts of the HEGRA facility complement each other, since they are designed to operate in adjacent energy regions. The important advantage of locating the telescopes in the Canary Islands, apart from the assistance of the Western partners in the fabrication of several of the components, is the nearly ideal weather and atmospheric transmittance at the altitude of the facility—2200 m above sea level.

A similar system of two mirror telescopes separated by 260 m is planned to be built at Tien Shan within the framework of the SHALON project. V. G. Sinitsina (FIAN) spoke of this project. An important addition to the mirror telescopes is that they are surrounded by hexagonal rings of 6 wide-angle Čerenkov detectors with a radius of 130 m for locating the axis and determining the arrival direction of EAS.

The original proposal of an experiment to study extensive air shower cores in a mountain lake by an acoustic method was put forth by A. Yu. Medvedev (MIFI). Its uniqueness lies in the possibility of studying the core structure of large EAS. The facility should be an open array of underwater antennas at depths to 30 m at intervals of 300–500 m. Calculational and experimental studies as well as field tests of an antenna prototype confirm the validity of the proposed experiment. The building of a 3 km^2 area facility, for which 30 antennas are required, has been proposed as the initial step.

The equipment and detectors of the ANI facility were described in reports by G. Ts. Avakyan (ErFI), Ya. Oleĭnichak (Poland) and N. A. Arvanov (FIAN). These include ionization and proportional chambers and the x-ray portion of the hadron module of the ANI prototype, the use of a video digitizer for analyzing the tracks in the spark chambers of the ANI magnetic spectrometer and an extended scintillation detector with excellent light gathering uniformity along a length of 4.5 m. It is proposed to use this scintillation detector as a module, a large number of which will be placed beneath an ionization calorimeter in order to investigate the penetration capability of hadron showers.

Methods for the analysis of experimental data, based on pattern recognition theory, have been successfully developed for several years at ErFI. Work to determine the parameters of strong interactions was described at this school by G. Z. Zazyan (ErFI). A method was suggested for the simultaneous analysis of model and experimental data in the multidimensional space of the measured properties of EAS. This method makes it possible to determine the kinds of primary particle with an efficiency of 70–80% by solving the inverse problem and to determine the energy of the primary particle with an accuracy of 25%, and then to evaluate certain parameters of the interaction of protons and nuclei with the nuclei of air atoms. In particular, the possibility of evaluating the inelastic cross section and the inelasticity coefficients in pA-interactions was discussed.

An idea for an estimation of the energy of gamma rays from point sources by means of Čerenkov telescopes, proposed in a joint effort of ErFI and the State University of Altai (AGU), from which A. K. Konopel'ko attended, involves these same nonparametric methods. The idea is based on the strong correlation of light intensity with initial energy in the case of a separate analysis of events in terms of zones, determined from the location of the cell with maximum intensity within the photochamber. The high accuracy of the estimate (25–30%), together with the use of the multidimensional background discrimination technique will make it possible not only to study the spectra of discrete sources in the 0.1–10 TeV region but also to pose the problem of studying the interaction of "beams" of gamma rays of very high energies with atoms of the atmosphere.

As usual, the theoretical efforts in gamma-ray astronomy occupied an important place at this school. Calculations of the photonuclear mechanism of generating cosmic gamma radiation, about which I. V. Moskalenko (NIIYaF MGU) spoke, have undergone considerable development during the time since the last school. He showed that one can expect an appreciable number of complex nuclei ($A > 12$) in the corpuscular radiation of neutron stars. The photonuclear mechanism may dominate in a certain energy range over other mechanisms for the generation of gamma radiation. Data on the energy spectra of gamma rays from the Cygnus X-3 and Crab nebula sources were described and the characteristics of the medium surrounding these sources were obtained.

A model of the pulsating gamma radiation from binary x-ray sources was proposed in a report by A. N. Atoyan (ErFI), in which it is suggested that this radiation arises as a result of the bombardment of cloud targets, ejected from the companion star, with a beam of relativistic particles in steady-state acceleration by the pulsar. All features of the gamma radiation of a source such as Hercules X-1 are explained in a natural manner within the framework of this model: a) the already-mentioned blue shift of the frequency of the gamma pulsations with respect to the frequency of the x-ray pulsations; b) the sporadic nature of the radiation with a typical duration of less than 1 hour; c) the lack of correlation between the gamma flashes and the phase of the orbital rotation; d) the possibility of observing a gamma flash in the total eclipse phase of the x-radiation.

The high-energy gamma rays and electrons, produced in the source, generate an electromagnetic cascade as they pass through the low-energy photon field. The cascade processes can determine to an appreciable degree the shape of the energy spectrum of the gamma rays from the source. Although this problem has been examined many times, the final solution to it has yet to be found, in view of the contradictions between the results obtained by different investigators. Reports by V. V. Sizov (NIIYaF MGU) and A. A. Lagutin (AGU) were devoted to this problem at the school. Simple relations are established between the spectra of cascade particles, the parameters of the photon field, and of the primary gamma radiation. It is shown that the energy spectra of the cascade photons developed in a sufficiently dense photon field with a power law spectrum are steeper than a cascade spectrum developed in a monoenergetic field. The slope of this spectrum within some energy region, determined by the cutoff limits of the power-law spectrum of the photon field, is one unit steeper than the spectral index of this field. An estimate of the effect of a magnetic field on the cascade characteristics is given in the first report. In addition to the mean energy spectra of the photons, the variances of their number and the fractions of energy carried by them have been obtained for the first time in the second report. The problem of the sensitivity of the characteristics of a cascade, developed within the photon field, to variations of this field about an average value, describable by a power-law function, is posed and solved. The sensitivity of different portions of the spectra of cascade photons to the structure of the photon field is also investigated.

As suggested by the organizers of the school, considerable importance was attached to discussing the problems associated with the existence of "new physics" at high energies. Interest in this problem was heated up considerably by the unusual properties of showers from Hercules X-3. The neutral radiation of this source generated showers in the atmosphere that were essentially no different in their muon content from normal hadron showers. This similarity of properties has also been observed in certain other sources, for example, the already-mentioned flash of Hercules X-1 in May–July 1986. As a rule, all attempts to explain this phenomenon have reduced either to an increase in the magnitude of the photonuclear cross section, or to the introduction of new neutral quasistable hadrons. Either of these suggestions should lead to a change in the picture for the development of EAS at high energies. We have already mentioned here reports in which these questions have been touched upon to some degree or another (S. I. Nikol'skiĭ, A. Osawa, E. I. Tukish and S. B. Shaulov). There were also reports specially devoted to the possible existence of new particles.

Experimental indications for the existence of new stable hadrons with a mass of ~ 100 GeV in cosmic rays were presented in the reports of Yu. N. Bazhutov (TsNIImash) [Central Scientific-Research Institute of Mechanical Engineering]. A new "mirror" version $U(1)\times SU(2)_L \times SU(2)_R \times SU(3)$ of the gauge model has been proposed, in which these hadrons are interpreted. The properties of interactions of the new hadrons with nucleons and atomic nuclei have been established. It is shown that these properties make it possible to match theory with the rigid cosmochemical constraints on the existence of new stable particles. A program of possible experiments at the ANI complex to search for these hadrons has been proposed.

A curious consequence of the possible existence of heavy stable hadrons if they carry a negative electric charge is the possibility that they can serve as a catalyst of the cold fusion reaction similarly to μ-catalysis. Experiments have begun at TsNIImash to study cold fusion in titanium electrodes electrolytically saturated with deuterium. Yu. P. Chertov reported on these matters.

Another consequence of the hypothesis of the presence of heavy stable hadrons in the neutral radiation of Cygnus X-3 is the possibility for explaining the wide angular distribution of muons from this source, observed in the SOUDAN-1 and NUSEX underground experiments. A report on this subject was presented by G. S. Martirosyan (ErFI). A distortion of the arrival direction of EAS from Cygnus X-3 is associated with a delay of the arrival of heavy particles with respect to photons and with the movement of the observer as a result of the diurnal rotation of earth.

Experimental evidence for the existence of heavy decaying particles was presented by G. Zh. Oganyan (ErFI). An event was recorded in the calorimeter of the PION facility when two cascades were observed with energies of 0.5 and 0.6 TeV, leaving from one point at an 80° angle. The mass of the neutral decaying particle giving rise to these two cascades is estimated to be $M_x > 600$ GeV.

A. Yu. Khodzhamiryan (ErFI) presented a critical review of the problem of anomalous showers from Cygnus X-3. In his opinion the experimental data on radiation flashes from Cygnus X-3 are still so contradictory that in the absence of any indications of the appearance of "new physics" in accelerators it is scarcely worthwhile to set up a world of new particles in cosmic rays in order to explain contradictory experimental facts. With respect to the large value of the photonuclear cross section at high energies is concerned, the use of the methods of perturbation theory in QCD down to such small p_T values as 1 GeV/c is dubious, and as a consequence, there is doubt as to the correctness of the calculations of $\sigma_{\gamma N}$ that have been made. In any case the question of the value of $\sigma_{\gamma N}$ at high energies will be answered experimentally in the near future on the HERA and UNK accelerators.

Since the school lasted until just after summer vacation, which is usually a period during which various conferences are held, information about these conferences which might be of interest for the school attendees was given out. The Scientific Director of the school S. G. Matinyan (ErFI) spoke about the 25th International Conference on High-Energy Physics in Singapore, S. A. Slavatinskiĭ (FIAN) spoke about the International Symposium on the interactions of cosmic rays of ultrahigh energies at Tarbe (France), and T. L. Asatiani (ErFI) reported on the 7th European Symposium on Cosmic Rays at Nottingham (England).

The chairman of the organization committee É. A. Mamidzhanyan spoke some final words to the school. In summarizing the school it can be pointed out that the lag in the Soviet experimental base and the development of high-energy physics and gamma-ray astronomy and, in particular, the slowdown in the rate of building the ANI complex, have also had an effect on the scarcity of new experimental results reported in the school. The predominance of theoretical and interpretational works was not completely in accord with tradition, which can only be overcome by the joint efforts of the entire community of physicists, working in these extremely interesting and crucial areas.

Translated by Eugene R. Heath