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O. DOVZHENKO, V. ZATSEPIN, E. MURZINA, S. NIKOLSKY,

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Abstract

Full Text

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O. DOVZHENKO, V. ZATSEPIN, E. MURZINA, S. NIKOLSKY, I. RAKOBOLSKAYA, and E. TUKISH

INVESTIGATION OF EXTENSIVE ATMOSPHERIC SHOWERS OF COSMIC RADIATION

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In the autumn of 1955, at an altitude of 3860 m above sea level, we carried out a series of measurements to investigate the energy characteristics of extensive atmospheric showers of cosmic rays.

The layout of the experimental installation is shown in Fig. 1. Fourfold coincidences of discharges in two groups of counters a, separated from one another by a distance of $\sim$ 2 m, selected extensive atmospheric showers produced by primary particles with energies $2 \cdot 10^{13}$—10^{16} eV. In all, about $4 \cdot 10^4$ extensive atmospheric showers were recorded. To determine the point of passage of the axis and the number of charged particles in each registered shower, a large number of counters connected to a hodoscopic device* was used. The arrangement of 33 groups of hodoscopic counters is shown in Fig. 1. Each group of counters g consisted of 24 counters with an area of 100 cm^2. In addition, at three points located at the vertices of a triangle at a distance of 19 m from the center of the installation, there were another 108 hodoscopic counters with an area of 330 cm^2 and 72 counters with an area of 22 cm^2 each.

Fig. 1. Diagram of the central part of the installation.
a –control groups of counters; b–Wilson chamber; g –groups of hodoscopic counters; v, d, e –groups of ionization chambers

In cases where the core of an extensive atmospheric shower passed within the limits of the installation shown in the plan, the shower axis could be determined with an accuracy of up to 1 m, under the assumption of axial symmetry of the shower, as was first done in work (1). The spectrum of showers recorded by our installation according to the number of charged particles for extensive atmospheric showers whose axes pass no farther than 5 m from the center of

Fig. 2. Probability of registering cores of extensive air showers with different numbers of particles in the shower N

Figure 2: Fig. 2. Probability of registering cores of extensive air showers with different numbers of particles in the shower N

the installation is shown in Fig. 2. The error in determining the total number of particles in such showers was $\sim 10\%$. In the other cases of registration of extensive atmospheric showers, the point of passage of the axis and the number of particles in the shower could be determined from the ratio of the densities of the flux of charged particles at the center of the installation and at three points located 19 m from the center of the installation, using the available experimental

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* We used the GK-7 circuit developed by L. N. Korablev (2).

further data on the spatial distribution function of shower particles ([3]). The error in determining the indicated shower characteristics by this method reached 40%.

The absorption of the penetrating component of extensive air showers in the ground was observed with the aid of counters connected to a hodoscopic device and located directly beneath the central part of the installation, in a shaft at depths of 8 and 16 m water equivalent. In contrast to earlier measurements ([4]), at both measurement levels there were detectors of penetrating particles, which consisted of three rows of hodoscopic counters separated from one another by filters (6 cm Pb). The use of such detectors made it possible to study both the energy spectrum of the μ-meson component of extensive air showers and the absorption of the flux of shower particles in dense matter.

Fig. 2. Probability of registering cores of extensive air showers with different numbers of particles in the shower N.

As the measurements showed, the energy spectrum of μ-mesons at distances < 10 m from the shower axis, for the μ-meson energy interval $E = 1.5$–3.5 Bev, can be expressed in the form $\sim 1/E^m$, where $m = 0.27 \pm 0.06$, which is in complete agreement with the work ([4]).

An interesting result was obtained in observing cases of the passage of cores of extensive air showers through a detector of penetrating particles located at a depth of 800 g/cm^2 water equivalent. The expected number of cases was calculated on the assumption that the shower has one core and that the transverse dimensions of the core may be neglected; here the transverse dimensions of the core are understood as the region in which particles with energy $\gtrsim 5 \cdot 10^{11}$ ev are distributed. Comparison of the calculated number of cases with the observed number showed complete agreement of these numbers for showers produced by primary particles with energy $E_0 < 6 \cdot 10^{14}$ ev*. For showers produced by primary particles with energy $E_0 > 6 \cdot 10^{14}$ ev, the number of cases in which the

Figure 3: Distribution of ionization pulses in chambers during passage of the core of an extensive air shower.

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shower core passed through the detector exceeded the expected number by several times. This excess can be explained if one assumes that, in extensive air showers produced by primary particles with energy $> 6 \cdot 10^{14}$ ev, the transverse dimensions of the shower core, i.e., of the region of concentration of particles with energy $\gtrsim 5 \cdot 10^{11}$ ev, are $\sim$ 1–2 m, which does not contradict the available data on the spatial distribution of charged particles near the axis of an extensive air shower ([3]).

The spectrum of the electron-photon component in the central regions of the extensive air showers observed by us was investigated with the aid of a large Wilson chamber described in ([5]). The position of the Wilson chamber relative to the hodoscopic counters is shown in the diagram (Fig. 1, b). The energy of electrons and photons was determined from the total number of particles in the cascade shower arising when electrons and photons passed through the lead plates of the Wilson chamber. By this method the spectrum of the electron-photon component was measured in the energy interval $2 \cdot 10^8$–10^{10} ev for various distances from the shower axis. The experimentally obtained spectra of the electron-photon component in the interval of distances from the shower axis of 4 m proved to be depleted in high-energy electrons and photons in comparison with the predictions of cascade theory, if the energy of the π^0-mesons responsible for the formation of the electron-photon component of the showers registered by us is taken to be 10^{12} ev. The discrepancy between the exper–

* The energy of the primary particle E_0 is assumed to be $2.5 \cdot 10^9 \overline{N}$, where $\overline{N}$ is the total number of charged particles at the observation level.

with experiment and calculation can be eliminated if one assumes a substantial role of π^0-mesons with energy $\lesssim 10^{10}$ eV in the formation of the electron-photon component of the shower.

Measurements of the energy fluxes carried by the nuclear-active and electron-photon components of extensive air showers, as well as investigations of the structure of the shower core, were carried out using 30 ionization chambers. We used cylindrical ionization chambers of two sizes. Twelve ionization chambers 18.5 cm in diameter and 42 cm long were arranged in two groups of 6 chambers each (Fig. 1, *e*). The remaining ionization chambers had a diameter of 22.5 cm and a working length of 96 cm. The arrangement

Fig. 3. Distribution of ionization pulses in the chambers during passage of the core of an extensive air shower. The magnitude of the ionization is expressed as the number of relativistic particles passing along the mean chord of the ionization chamber. The arrangement of ionization chambers 1–24 is shown at

upper left. The shower axis, as determined by the hodoscope, passes in case A near chamber No. 4, and in case B near chamber No. 19.
A—number of particles in the shower $N = 2.8 \cdot 10^4$, B–$N = 1.5 \cdot 10^6$.

of 3 groups of 6 ionization chambers is indicated in the diagram of Fig. 1 by the letters d and e. The chambers were filled with chemically pure argon to a pressure of 4 atm.

The radio-engineering apparatus* used by us permitted measurement of the amplitude of the electronic component of ionization pulses in the interval of ionization values from $6 \cdot 10^3$ to 10^8 ion pairs, which corresponded to ionization produced by the passage, along the mean chord of the chamber, of from one to $1.5 \cdot 10^4$ relativistic particles.

Filters of various substances and variable thickness were placed above the ionization chambers. Measurements were carried out with lead filters of thickness 1; 2; 3; 5; 10; 20; 50 and 80 cm; with iron filters of thickness 1.1; 3.5 and 7.5 cm; with a filter of aluminum and graphite of total thickness 230 g/cm^2; and also with a more complicated filter consisting of 3 cm of lead placed directly above the chambers, 80 cm of graphite, and 2 cm of lead covering the graphite from above.

The use of the indicated set of filters made it possible to measure the energy flux carried by the electron-photon component of the shower at various distances from its axis, and to determine the energy of the nuclear-active shower particles. The energy of the particle of highest energy in the core of extensive air showers with number of particles $< 10^5$ amounts on average to 10% of the energy of the electron-photon component of the shower at the observation level. The remaining nuclear-active particles in showers with the indicated number of particles are distributed according to the law $\sim 1/E^n$, where E is the energy of the nuclear-active particles, $n = 0.9 \pm 0.2$. The energy carried by these particles reaches 60% of the total energy of the shower

* The apparatus was developed by L. N. Korablev.

at the observation level (subtracting the energy carried by μ-mesons and neutrinos).

As an illustration, we shall give one of the cases of registration of a "leading" particle under a filter consisting of 3 cm of lead, 130 g/cm^2 of graphite, and 2 cm of lead. Multiplication in a certain layer of lead (3 cm) of the electron-photon component arising as a result of the nuclear interaction of high-energy particles in the graphite made it possible to estimate the energy of the nuclear-active particle in each individual case of shower registration. In the present case (Fig. 3 A) the energy of the "leading" particle may be estimated from the ionization burst in chamber No. 3 as 10^{12} eV, which amounts to $\sim 15\%$ of the total energy of the electron-photon component of the shower at the observation level.

The cores of extensive air showers with a number of particles $> 10^5$ generally have a more complex structure. Here, in contrast to showers with a number of particles $< 10^5$, one does not observe a single energetically distinguished particle, but rather several nuclear-active particles comparable with one another in energy are detected (Fig. 3 B). The transverse dimensions of such a region in the showers we observed are 1–3 m. This result coincides with the results of observations of the cores of extensive air showers in a mine and agrees with the earlier assumption[6] concerning a possible change in the character of the elementary interaction at an energy of the interacting particles $\sim 3 \cdot 10^{14}$ eV.

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P. N. Lebedev Physical InstituteAcademy of Sciences of the USSR

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Note: Figure translations are in progress. See original paper for figures.