



Soviet-era science, translated into English

Physics

L. T. Baradzei, V. I. Rubtsov, Yu. A. Smorodin, M. V. Solov' ev,

1957

SovietRxiv

View the original and related papers at <https://sovietrxiv.org/items/ru-195701.30792>

Source: Math-Net.Ru and CyberLeninka. Machine translation. Verify with the original.

Abstract

Full Text

Physics

L. T. Baradzei, V. I. Rubtsov, Yu. A. Smorodin, M. V. Solov' ev,
B. V. Tolkachev, and Z. I. Tulinova

Interaction of Cosmic-Ray Protons with Energy about 10^{10} eV with Lead Nuclei

(Presented by Academician D. V. Skobel' tsyn, 5 March 1957)

Studies of the interactions of cosmic-ray protons with nuclei of lead atoms were carried out at an altitude of 9000 m by means of a Wilson chamber placed in a magnetic field of strength 9200 oersteds. The control scheme of the chamber is shown in Fig. 1. Expansion in the chamber occurred when at least one penetrating charged particle passed through the rows of counters $C_1C_2C_3C_4C_5$ and at least two charged particles passed through the telescopes in row B.

In order to exclude interactions caused by π -mesons, electron-nuclear showers generated in a lead plate by a single charged particle were considered. Thirty-eight such cases were selected. Characteristic photographs of showers are shown in Fig. 2. From the photographs, measurements were made of the spatial arrangement of particle tracks, measurements of the momenta of charged particles, and also estimates of their ionizing power. The maximum measurable momentum was $3 \text{ BeV}/c$ for tracks with an average length of about 6 cm. The accuracy in determining the direction of motion of a particle was about 2° . The ionizing power of particles was determined visually.

Table 1 shows the distribution of showers according to the number of particles n in the shower. The first line of the table gives the sum of the number of charged π -mesons generated in the showers and of protons whose ionizing power in the chamber does not differ from the minimum (proton momentum more than $600 \text{ MeV}/c$).

Table 1

n	1	2	3	4	5	6	7	8	9
Number of showers	2	7	9	5	8	1	4	1	1

The small number of recorded showers with a small number of particles is explained by the selection imposed by the chamber-control scheme. The mean number of particles per interaction, n , is 3.9 ± 0.3 .

Fig. 1. Experimental arrangement

Figure 1: Fig. 1. Experimental arrangement

The experimental data make it possible to obtain some information about the principal components of electron-nuclear showers.

Electrons could be separated from mesons and heavier particles in the following way. In the momentum region below 100 MeV/c, they possess minimum ionizing power. Particles with momentum greater than 100 MeV/c were assigned to the electron component if they emerged from the plate in the form of electron-positron pairs or were accompanied by a cascade bundle of electrons.

Figure 3a gives data on the energy distribution of electrons. If this spectrum is described by a power law of the form $dN/dE \sim E^{-\gamma}$, then the exponent γ turns out to be variable. Its value changes from 1 in the region of small energies to 2.5 in the region of energies of about 1 BeV.

In the region of momenta below 600 MeV/c, mesons could be separated from protons and heavier particles by the magnitude of the momentum and the ionizing ...

capability. In this region the ratio of the number of mesons with positive charge to the number of negatively charged mesons was determined; it was found to be 1.2 ± 0.4 . In the momentum region greater than 600 MeV/c, all negatively charged particles, except electrons, were counted as π^- -mesons, while the number of π^+ -mesons was taken to be $N_{\pi^+} = 1.2 N_{\pi^-}$.

Figure 3b presents the energy distribution of the mesons. The solid curve represents the distribution of π -mesons generated in a photographic emulsion exposed in the atmosphere ⁽¹⁾. The spectra are normalized to the total number of particles. Within the errors, the two distributions coincide. If the distribution obtained is described by a power law, then in the energy region from 200 to 2000 MeV the experimental data are best satisfied by the value $\gamma = 1.6$. The mean number of charged mesons with energy < 2 BeV is 2.8 ± 0.3 per interaction.

Figure 3c shows the energy distribution of protons and heavier particles, which in what follows we shall call δ -particles. For comparison, the solid curve gives the distribution of protons, deuterons, and tritons according to photographic-emulsion data ⁽¹⁾ (normalized to the total number of particles). The distributions do not differ within the experimental errors. In the energy region from 900 to 1300 MeV the distribution obtained can be described by a power law with exponent $\gamma = 1.5$. The number of particles in this energy region is 2 ± 0.2 per interaction.

Fig. 1. Experimental arrangement

Let us consider the distribution of energy among the various components of the showers.

Fig. 3. Energy distribution of particles emitted in nuclear interactions in lead:
a –electrons, b – π^\pm -mesons, c – δ -particles

Figure 2: Fig. 3. Energy distribution of particles emitted in nuclear interactions in lead: a –electrons, b – π^\pm -mesons, c – δ -particles

Charged mesons with energy < 2 BeV carry away an energy equal on average to 1150 ± 130 MeV per interaction. The spectrum of π -mesons shown in Fig. 3b may be extrapolated into the energy region > 2 BeV by a power law with exponent $\gamma = 2.5$. This value coincides with the value of γ in the energy spectrum of π -mesons generated in photographic plates ⁽¹⁾, and also with the generation spectrum of π -mesons in the atmosphere ^(2,3). According to the extrapolation, the number of mesons with energy > 2 BeV is 0.14 per interaction, and the energy carried by them is about 800 MeV. Thus, all charged mesons carry on average 2 BeV of energy per interaction.

The energy of π^0 -mesons can be determined from the energy of electron-photon showers generated by photons arising from the decay of π^0 -mesons. The energy of the electrons, whose distribution is given in Fig. 3a, is 270 ± 70 MeV.

Photons formed as a result of the decay of π^0 -mesons traverse, in the lead plate, a path equal on average to 2 radiation units. For the photon energy interval from 50 to 1000 MeV this path is close to the path over which the maximum development of the shower occurs. In the region of small electron energies, the observed energy spectrum of the electrons is close to the spectrum at the shower maximum from photons with energy 330 MeV, calculated in ⁽⁵⁾. In the region of large energies, according to calculations ^(4,5), the exponent of the electron spectrum coincides with the exponent of the energy spectrum of the π^0 -mesons. The observed electron spectrum satisfies this condition.

Extrapolating the electron spectrum in the region of higher energies according to the law $dN/dE \sim E^{-2.5}$, we find that electrons with energy > 2 BeV carry an energy of about 160 MeV per interaction. In the photographs one ...

an electron with energy > 2 BeV, traveling in a pair with a positron of energy 1.4 BeV. Thus, the total energy of the electrons amounts to 430 MeV per interaction.

In an equilibrium spectrum the ratio of the energy carried by photons to the energy carried by electrons is 1.3. The energy of the π^0 -mesons, equal to the total energy of the electron-photon cascade, therefore amounts to about 1 BeV per shower. The ratio of the energy carried by π^0 -mesons to the energy carried away by π^\pm -mesons turns out to be 1/2. The total energy carried away by both charged and neutral π -mesons amounts to about 3 BeV per interaction.

Fig. 3. Energy distribution of particles emitted in nuclear interactions in lead:
a –electrons, b – π^\pm -mesons, c – δ -particles

Charged δ -particles with energies in the interval from 90 to 1300 MeV carry away an energy of 700 ± 120 MeV per interaction. In the energy region > 1300 MeV,

the distribution of δ -particles shown in Fig. 3c can be extrapolated according to the law $dN/dE \sim E^{-3}$. Such an extrapolation agrees with photoemulsion data ⁽¹⁾. The number of δ -particles in this energy region is 0.13 per interaction, and the energy carried by them is about 300 MeV. Taking into account δ -particles with energies in the interval 25–90 MeV, whose number was extrapolated from the data presented in Fig. 3c, the energy carried away by charged δ -particles amounts to 1.1 BeV.

The energy of neutral δ -particles can be taken into account by assuming that the ratio of the number of neutrons to the number of protons is 1.5—the ratio of the number of neutrons to the number of protons in the lead nucleus. The total energy of the δ -particles then increases to 2.4 BeV per shower.

The experiments described do not provide information on particles with energy < 25 MeV, which produce the so-called “black” tracks. In the interaction of protons of energy about 10 BeV with an emulsion nucleus, the energy carried away by these particles is 280 MeV. For a lead nucleus this energy may increase in proportion to the linear dimensions of the nuclei and amount to about 400 MeV.

In the interactions under consideration, high-energy particles are emitted that have not yet been taken into account. The mean number of particles with momentum > 2 BeV/c is 0.81 ± 0.14 per interaction. According to the extrapolations made, the number of π^- -mesons and δ -nucleons in this momentum region is 0.27.

The excess of high-energy particles cannot be ascribed to charged π -mesons, since in that case the energy of the electron-photon component arising from the decay of the corresponding π^0 -mesons would have a value of about 2 BeV per interaction. In the experiment, there could have been detected

increase in the energy of the electron-photon component exceeding 20% of the indicated value.

Therefore the excess of high-energy particles, equal to 0.5 particles per interaction, must be ascribed to protons. It should be noted that in 16 of the 38 recorded showers a single particle with momentum > 2 BeV is observed. It is reasonable to assume that high-energy neutrons are emitted in approximately the same number as protons.

The minimum value of the total energy of the particles after the interaction is then about 8 BeV.

If it is assumed that the emitted high-energy nucleons have a power-law spectrum with exponent $\gamma = 2.5$, coinciding with the spectrum of the incident protons, then the mean energy of such high-energy nucleons will be

$$\frac{\gamma - 1}{\gamma - 2} E_{\text{gr}} = 4 \text{ BeV};$$

the mean interaction energy will then be 11 BeV.

Methods of estimating the mean energy from the flux of shower-producing particles, equal to $0.046 \text{ particles cm}^{-2} \text{ min}^{-1} \text{ sr}^{-1}$, from the mean multiplicity, and from the angular distribution of the shower particles lead to a value of the primary-particle energy of 10-13 BeV.

Thus, a proton with energy of about 10 BeV, in interacting with a lead nucleus, loses on average from $2/3$ to $1/2$ of its energy. Charged and neutral π -mesons carry away about $1/3$ of the energy of the incident proton. Approximately the same energy is carried by δ -particles.

Moscow State University
named after M. V. Lomonosov,
P. N. Lebedev Physical Institute
Academy of Sciences of the USSR

Received
21 XII 1956

CITED LITERATURE

1. *Cosmic-Ray Physics*, ed. J. Wilson, IL, 1954, ch. 1.
2. M. Sands, *Phys. Rev.*, **77**, 180 (1950).
3. G. M. Garibyan, I. I. Goldman, *ZhETF*, **26**, 257 (1954).
4. A. G. Carlson, I. E. Hooper, D. T. King, *Phyl. Mag.*, **41**, 701 (1950).
5. I. P. Ivanenko, Dissertation, Moscow State University, 1956.

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

Source: Math-Net.Ru and CyberLeninka. Machine translation. Verify with the original.