INTERACTION OF COSMIC PIONS WITH GRAPHITE NUCLEI

I. N. Erofeeva, L. G. Mishchenko, V. S. Murzin, and L. I. Sarycheva
P. N. Lebedev Physics Institute, USSR Academy of Sciences
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Investigations of nuclear-active particles at mountain altitudes [1 - 3], using apparatus described in [1, 2], having been going on for a number of years.

1. The setup, which consists of an ionization calorimeter, a cloud chamber, and hodoscopic counters, makes it possible to measure the energy (E_0) of the nuclear-active particles interacting in a graphite filter, the energy (E_γ) transferred in this interaction to the electron-photon component, the multiplicity of the secondary (n_s) and of the newly created (n_c) particles and their emission angles (θ_i), and also the presence of charge in the generated particle. From these primary characteristics, new parameters of the interaction were calculated, namely the Lorentz factor (γ_c) of the C-system under the assumption that the nuclear-active particle collides with a target having a nucleon mass ($\gamma_c = \sqrt{E_0/2m_p}$); the Lorentz factor ($\gamma_s$) of the symmetrical system [4] ($\log \gamma_s = - \langle \log \tan \theta_i \rangle$), the average energy of the secondary charged particles $\langle \varepsilon \rangle = E_{\pi^\pm}/n_c$, (where $E_{\pi\pm} = 0.35 \quad \operatorname{cosec} \theta_i$ (GeV) is the energy transferred to the secondary particles), the target mass $m_t = m_p \langle \gamma_c/\gamma_s \rangle^2$, and the variance $\sigma = (\langle x_i - \langle x \rangle \rangle^2)^{1/2}$ characterizing the angular distribution of the secondary particles in coordinates $x_i = \log \tan \theta_i$.

2. Altogether 60 interactions between nuclear active particles having an average energy of approximately 200 GeV and graphite were recorded. In 41 cases, it was possible to determine whether the particle causing the shower was charged.

A different method was used to separate the pions from among the charged primary particles. It was proposed that at mountain altitudes, where measurements were carried out, the

Average shower characteristics

Nature of primary	Shower number	n_c	σ	γ_s/γ_c	m_t 1)	$\langle \varepsilon \rangle / E_0$
Neutral	12	11.6 ± ±2.1	0.40 ± ±0.02	1.17 ± ±0.20	$\sim m_p$	0.03 ± ±0.005
Corresponding charged	12	12.0 ± ±1.9	0.42 ± ±0.02	1.18 ± ±0.22	$\sim m_p$	0.04 ± ±0.007
Pion interactions	17	7.2 ± ±1.4	0.28 ± ±0.04	3.05 ± ±0.50	145 $\pm^{55}_{40}$ MeV	0.07 ± ±0.01
Incl. asymmetr. forward	11 2)	4.5 ± ±0.5	0.27 ± ±0.05	4.00 ± ±0.41	90 ± ±20 MeV	0.10 ± ±0.01

1) In the calculation of m_t we introduced a correction that takes into account the spectrum of produced pions.

2) The low values of n_c and m_t for the interaction with forward asymmetry bay be due to the small admixture (about 3 cases) of diffraction generation processes.

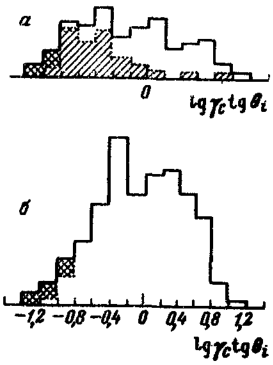

Fig. 1

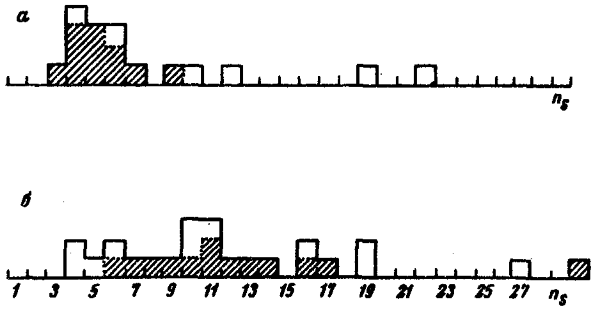

Fig. 2

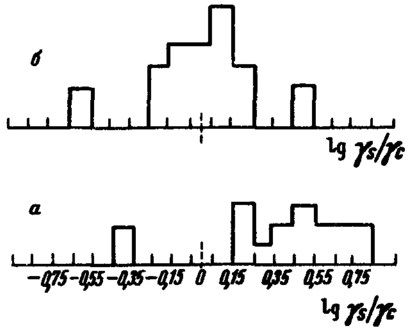

Fig. 3

Fig. 1. Angular distribution of the shower particles in coordinates $X = \log \gamma_c \tan\theta_i$: a) for 17 "pion" interaction, the shaded is distribution is for 11 showers having an asymmetrical angular distribution in the C system($\gamma_s/\gamma_c > 2$); b) for 24 "nucleon" interactions. The double hatching on both diagrams denotes the "conserved" primary particles emitted at an angle $\theta_i \leq 0.5°$.

Fig. 2. Distribution of secondary particles by multiplicity: a) for 17 "pion interactions, the shaded distribution is for 11 asymmetrical showers; b) for 24 "nucleon" interactions, the shaded distribution is for 12 showers due to charged primary particles.

Fig. 3. Distribution with respect to the parameter $\log \gamma_s/\gamma_c$: a) for pion interactions, b) for "nucleon interactions.

number of protons equals the number of neutrons, and also that the protons and neutrons interact in the same manner with the graphite nuclei. Showers due to charged primary particles and having similar characteristics were chosen for 12 events produced by neutral particles. Following such a subtraction operation, it can be assumed that in 80 - 90% of the cases, the remaining showers due to charged particles are produced by pions.

3. The table lists the main characteristics of 41 interactions, which are combined into groups in accordance with the proposed nature of the primary particle.

The last line gives data for 11 showers (out of 17 pion interactions) having a strongly asymmetrical angular distribution relative to the forward direction ($\gamma_s/\gamma_c > 2$).

Figure 1 shows the angular distribution, with scale $X = \log \gamma_c \tan\theta_i$, for nucleon interactions (Fig. 1b) and for pion interactions (Fig. 1a). The double hatching shows the "conserved" primary particles emitted at angles $\theta_i \lesssim 0.5°$. The single hatching in Fig. 1a shows the particles produced in 11 pion-interaction showers having sharply asymmetrical angular distributions.

For the same groups, Fig. 2 (a and b) shows the distribution with respect to the multiplicity n_s, and Fig. 3 shows the distribution with respect to the parameter $\log \gamma_s/\gamma_c$. The average value of this parameter determines the mass of the targe $m_t = m_p \langle\gamma_c/\gamma_s\rangle^2$.

It can be concluded from the presented data that the pion interactions differ in character from the showers produced by the nucleons.

4. The most characteristic feature of pion interactions is the occurrence of an appreciable number of showers that are asymmetrical forward in the C-system, and become symmetrical

in the system with the target mass $m_t = m_\pi$ (last line in the table). In nucleon interactions, such showers occur in exceptional cases.

The observation of asymmetrical showers due to pions makes it possible to tie together a number of other features noted by us earlier [5, 6] in pion interactions.

If the nucleon-nucleon and pion-nucleon interactions are the same in the symmetrical system, then the average particle energies in the L system will obviously differ by the factor γ_s/γ_c:

$$\langle\epsilon\rangle_\pi/\langle\epsilon\rangle_p = \langle\gamma_s/\gamma_c\rangle \sim 3,0/1,2 = 2,5,$$

where $\langle\epsilon\rangle_\pi$ and $\langle\epsilon\rangle_p$ are the average energies of the pions in the L-system in the pion and nucleon interactions, respectively.

It follows therefore that the average multiplicity of the secondary particles in pion interaction should be smaller than in nucleon interactions. If we assume that the same fraction of energy is transferred to the common system, $\langle k\rangle = \langle k\rangle_\pi = \langle k\rangle_p$, then

$$\frac{\langle n\rangle_\pi}{\langle n\rangle_p} = \frac{\langle k\rangle_\pi \langle\epsilon\rangle_p}{\langle\epsilon\rangle_\pi \langle k\rangle_p} \sim (2,5)^{-1}$$

(see the table and the multiplicity distribution in Fig. 2).

It is interesting to note that an investigation [7] reported in this issue and performed with the Serpukhov accelerator at 50 GeV energy confirms the existence of showers due to pions, with properties described in the present article, is confirmed (the presence of a large percentage of showers that are asymmetrically forward and have a low multiplicity).

[1] I. N. Erofeeva, L. G. Mishchenko, V. S. Murzin, and L. I. Sarycheva, Proc. Int. Conf. on Cosmic Rays, London, 2, 831 (1965).

[2] I. N. Erofeeva, L. G. Mishchenko, V. S. Murzin, and L. I. Sarycheva, Izv. AN SSSR, ser. fiz. 30, 1624 (1966).

[3] I. N. Erofeeva, L. G. Mishchenko, V. S. Murzin, and L. I. Sarycheva, ibid. 31,412(1967).

[4] G. Castagnoli et al., Nuovo Cimento 10, 1539 (1953).

[5] V. S. Murzin and L. I. Sarycheva, Kosmicheskie luchi i ikh vzaimodeistviya (Cosmic Rays and Their Interactions), Atomizdat 1968.

[6] V. S. Murzin and L. I. Sarycheva, Izv. AN SSSR ser. fiz., 1969, in press.

[7] G. B. Zhdanov, M. I. Tret'yakova, M. M. Chernyavskii, ZhETF Pis. Red. 9, 394 (1969) [this issue, p. 234].

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