Energy Spectrum of μ-Mesons in Extensive Atmospheric Cosmic Ray Showers

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The energy spectrum of μ-mesons in extensive atmospheric showers of varying primary energy was studied in the energy range from 0.3 to 3.5 Bev. The measurements were carried out at mountain altitudes. It was found that in the aforementioned energy range the energy spectrum of μ-mesons is independent of the energy of the primary particle which initiated the shower. The mean μ-meson energy decreases with the distance from the shower axis.

PREVIOUS experiments [1,2] on the absorption of the penetrating component of extensive atmospheric showers in a dense substance indicated that the energy spectrum of penetrating particles in extensive atmospheric showers near sea level can be represented by a law with an exponent ~ 0.6. This result was obtained by averaging the data over a wide interval of distances from the shower axis and over different energies of the primary particle. Nuclear passive (μ- mesons) as well as nuclear active particles of the penetrating component were recorded.

During the summer and fall of 1954, we carried out at Pamir (3,860 m above sea level) experiments to determine the nature of the energy spectrum of μ-mesons at three distances from the axis of an extensive atmospheric shower and made a comparison of μ-mesons spectra in showers of different primary energies. The energy of μ-mesons was determined from their absorption in lead and ground. The general experimental layout and the depth cross section of the pit are shown in Fig. 1. The control system (CS) consisted of three arrays of Geiger-Müller counters located above detectors of penetrating particles A, B and C, and also at 100 and 300 meters from them (Fig. 1). Above the detectors of penetrating particles there were placed a large number of hodoscopic counters for investigating the electron-photon component of the shower.[3]

The detector of penetrating particles A recorded μ-mesons with an energy $\geqslant 185$ Mev, detector B—μ-mesons with energy $\geqslant 1.7$ BeV, and detector C—μ-mesons with energy $\geqslant 3.5$ Bev. The area of the counters in detectors A, B, and C was 0.38, 2.4 and 2.4 m^2, respectively.

The use of detector counters connected to the hodoscopic arrangement permitted us to distinguish the passage of nuclear passive particles (μ-mesons) from the passage of nuclear active particles according to their shower producing ability. During the statistical treatment of the experimental data, we paid attention only to the cases of the recorded single

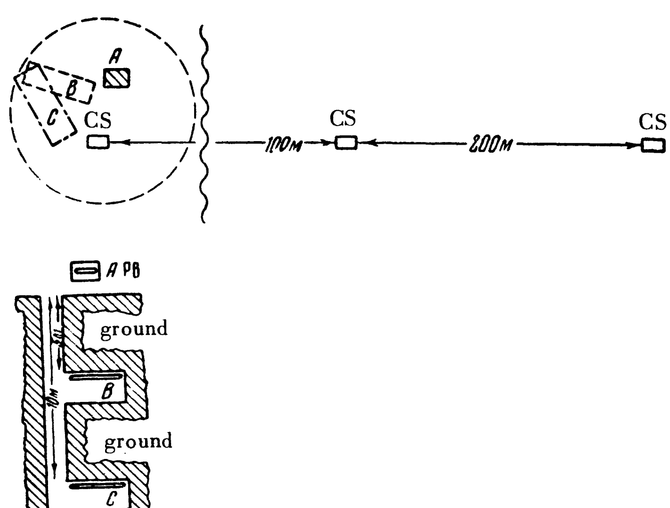

FIG. 1

penetrating particles not accompanied by a shower under the dense absorber. The number of μ-mesons thus recorded is lowered, since μ-mesons initiating a δ-shower are excluded from the analysis. As shown by measurements, the number of such mesons constitutes 10 ±2%. The variation in this number with an increase in the thickness of the absorber above the setup does not exceed the experimental error. The high resolution of the apparatus used practically excluded random coincidence discharges in the counters.

The flux density of μ-mesons was determined from the formula

$$\rho_\mu = \frac{1}{\sigma} \ln \frac{N_1 N_2}{N_1 N_2 - N_3} .$$

Here σ=counter area of one hodoscopic group; N_3= the number of recorded single μ-mesons; N_2=the number of recorded extensive atmospheric showers; N_1=the number of hodoscopic arrays of counters used during measurements.

The large system of hodoscopic counters located above the detectors of penetrating particles enabled us to determine the core location and the total number of charged particles in each recorded extensive atmospheric shower. The simultaneous determination of the core position, the total number of particles and the μ-mesons flux at various depth enabled us to determine the μ-meson energy spectrum for showers of varying energy. In all the cases investigated by us, the μ-meson energy spectrum can be represented by the law E_μ^{-n}, where E_μ—the energy of μ-mesons.

The value of the exponent n for showers with axes passing no farther than 8 m from detectors of penetrating particles are shown in Table 1. The energy of the shower-causing primary particle was assumed to be proportional to the total number of particles N in the shower ($E_0 \approx 2.5 \times 10^9 N$ ev)[5]. In the same table are shown the absolute values of the μ-meson flux density with the energy higher than that assigned to showers of a different primary energy.

As is seen from Table 1, the energy spectrum of μ-mesons in the interval 0.44 – 3.5 Bev near the core of extensive atmospheric shower does not depend on the energy of the primary particle. An analogous result is observed during the investigation of the periphery of an extensive atmospheric shower. In Table 2 are shown the values of the exponent n for extensive atmospheric showers with different primary energies, the axes of which are at a distance of 200-350 m from the detectors of penetrating particles.

Energy of the primary particle in 10^{14} ev	ρ_μ			Spectrum exponent n*
	$E_\mu \geqslant 0{,}185$ Bev	$E_\mu \geqslant 1{,}7$ Bev	$E_\mu \geqslant 3{,}5$ Bev	
1,25	0,23 ± 0,07	0,15 ± 0,03	0,16 ± 0,02	0,14 ± 0,17
1,75	0,27 ± 0,08	0,17 ± 0,03	0,16 ± 0,03	0,22 ± 0,10
2,6	0,38 ± 0,07	0,26 ± 0,03	0,18 ± 0,02	0,38 ± 0,07
4,2	0,36 ± 0,07	0,31 ± 0,03	0,25 ± 0,03	0,20 ± 0,05
6,2	0,50 ± 0,10	0,36 ± 0,05	0,31 ± 0,05	0,23 ± 0,07
10,0	0,65 ± 0,13	0,38 ± 0,05	0,36 ± 0,05	0,27 ± 0,12
15,0	0,55 ± 0,16	0,61 ± 0,08	0,42 ± 0,07	0,19 ± 0,25
20,0	1,00 ± 0,28	0,77 ± 0,11	0,62 ± 0,10	0,24 ± 0,02
35,0	1,21 ± 0,42	0,95 ± 0,18	0,76 ± 0,14	0,24 ± 0,02

*The value of the energy spectrum exponent was determined by the method of least squares.

Energy of the primary particle in 10^{14} ev	ρ_μ			n
	$E_\mu \geqslant 0{,}32$ Bev	$E_\mu \geqslant 1{,}7$ Bev	$E_\mu \geqslant 3{,}5$ Bev	
12	0,034±0,01	0,010 ±0,003	0,0044±0,0015	0,86±0,18
20	0,037±0,01	0,0084±0,0026	0,0056±0,0018	0,8 ±0,2
40	0,07 ±0,026	0,015 ±0,006	0,011 ±0,005	0,8 ±0,2

The comparison of the μ-meson energy spectrum at different distances from the axis of an extensive atmospheric shower gives:

Mean distance from the axis of a wide atmospheric shower, m	4	100	300
Mean value of the energy spectrum exponent, n	0,25±0,02	0,32±0,03	0,82±0,11

The cited data show that the μ-meson energy spectrum become softer with an increase in the distance from the axis of an extensive shower. Since a large part of μ-mesons in wide atmospheric showers is found at the shower periphery, then the energy spectrum of all μ-mesons in an extensive atmospheric shower at the observation level must be evidently still softer than the meson energy spectrum at a distance of 300 m from the shower axis. Actually, if one extrapolates to large distances, the observed change in the exponent of the energy spectrum with distance from the axis of an extensive atmospheric shower (see Fig. 2), and uses the experimentally obtained spatial distribution function for μ-mesons up to 1000 m in the form $\rho^{\mu} \sim R^{-2}$, then the value of the μ-meson energy spectrum exponent in an extensive atmospheric shower at the observation level is 1 ± 0.2 in the μ-meson energy range of 0.3 – 3.5 Bev.

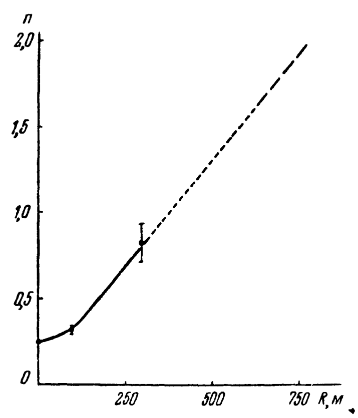

FIG. 2

In conclusion the authors wish to express their thanks to Professors N. A. Dobrotin and G. T. Zatsepin for their interest in the investigation.

Note added during proof-reading: After the paper has been submitted to the editor, we obtained supplementary data showing that in the energy interval 0.185 – 0.3 Bev the μ-meson energy spectrum cannot be represented in the form E_{μ}^{-n}, where n – constant value for a given primary energy and given distance from the shower axis. This result is explained by the finite lifetime of μ-mesons.

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