HODOSCOPE INVESTIGATION OF THE PENETRATING COMPONENT OF EXTENSIVE AIR SHOWERS

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A relation of the type $N_\mu \sim E_0^\kappa$ has been investigated for the flux of μ mesons possessing energies ≥ 0.41 Bev and moving 0 to 24 meters from the axis of extensive air showers. It is shown that for energies $1.54 \times 10^{14} \leq E_0 \leq 3.14 \times 10^{15}$ ev the exponent is $\kappa = 0.42 \pm 0.14$.

A dependence $N_\mu \sim E_0^\kappa$ has been established for the number of penetrating particles on the primary shower energy in several papers[1-3] devoted to the investigation of the penetrating component of extensive atomospheric showers under thin absorbers. We deemed it interesting to study an analogous dependence at our level of observation using available data on the flux density of μ mesons under lead in showers of various energies. The corresponding measurements were carried out in Tbilisi (~400 m above sea level) in the winter and spring of 1957.

The apparatus intended to fix the shower, to determine its magnitude, and to locate its axis was analogous to that used in reference 4. The only difference was that one of the lateral hodoscopes that were located symmetrically relative to the separating system was replaced by a penetrating-particle detector consisting of three rows of GS-60 hodoscopic counters, separated by layers of lead. Each row had 8 counters, and the total area of each row was 0.26 m^2. The minimum thickness of lead that a penetrating particle had to pass to produce a discharge in all three rows was 28 cm; a μ-meson energy greater than 0.41 Bev was thus necessary.

In the analysis of the hodoscopic data obtained with the penetrating-particle detector, an event was considered to be produced by a μ meson if:

(a) one counter was discharged in each of the rows in such a manner that the track of the particle could be reproduced,

(b) two or three neighboring counters in one of the rows operated together with single counters in the remaining rows. Thus μ mesons that produce a delta shower were also considered.

In the reduction of the material, we took into account the role played by different kinds of random coincidences of discharges in the detector counter. The contribution of random coincidences to the total number of μ mesons does not exceed 3% for all groups of investigated showers (the resolving time of the hodoscope was $\tau = 30\ \mu$sec, and the background of each counter was n = 1000 pulses/minute).

Based on the accuracy with which the magnitude of the shower was determined,[4] all extensive atmospheric showers were grouped in our experiments by the number of particles into the three groups shown in Table I.

TABLE I

Group No.	Interval	Average value	Primary energy
1	$7\cdot10^3$—$2.8\cdot10^4$	$1.4\cdot10^4$	$1.54\cdot10^{14}$
2	$2.8\cdot10^4$—$1.12\cdot10^5$	$7.2\cdot10^4$	$7.92\cdot10^{14}$
3	$1.12\cdot10^5$—$4.48\cdot10^5$	$2.85\cdot10^5$	$3.14\cdot10^{15}$

For each group of showers, the average density of the μ-meson flux was determined from the formula

$$\rho_\mu = \frac{1}{\sigma} \ln \frac{N}{N - N_\mu}, \qquad (1)$$

where σ is the area of one row of detectors, N the number of registered showers in a given group, and N_μ the number of showers of a given group in which a μ meson was registered. Of the total number of showers, N, we excluded those in which the μ-mesons could not be identified unambiguously. The data are summarized in Table II, which contains also the average distance r of the axis of the extensive atmospheric shower from the detector of the penetrating particles.

The values of the effective distance of the axis from the detector, given in Table II, were calculated in the following manner. If d is the distance between the detector and the center of the separating system, then the average distance R from the axis from the center of the separating system, the dis-

TABLE II

Energy of primary particle, ev	Total number of showers	Number of mesons	Density of meson flux, m^{-2}	Effective distance, m
$1.54 \cdot 10^{14}$	562	59	0.44 ± 0.06	10
$7.9 \cdot 10^{14}$	311	62	0.86 ± 0.13	10
$3.14 \cdot 10^{15}$	222	71	1.48 ± 0.25	10

tance r from the axis from the detector of the penetrating particle, and the azimuth angle φ are all related by

$$r^2 = R^2 + d^2 - 2Rd\cos\varphi. \quad (2)$$

We calculate N and N_μ from the following relations:

$$N = \iint_{R\varphi} P(R)\,R\,dR\,d\varphi; \quad (3)$$

$$N_\mu = \int_R\int_\varphi P(R)\,(1 - \exp\{-\rho_\mu(r)\,\sigma\})\,R\,dR\,d\varphi, \quad (4)$$

where P(R) is the distribution of the number of registered showers by distance from the axis of the center of the separating system, as obtained from the hodoscopic data, and $\rho_\mu(r)$ is the spatial distribution function of the μ mesons. For $\rho_\mu(r)$ we used an expression from the paper of Yu. Vavilov et al.[3] of the form $\rho_\mu = a/r^{0.6}$, at distances from 0 to 24 m.

Since our data did not include a single shower with an axis more than 24 m away from the center of the separating system, the use of a spatial distribution function in the form $\rho_\mu = a/r^{0.6}$ is well justified.

From the ratio of N_μ and N we calculated the probability of detector operation, $P(r) = N_\mu/N = 1 - \exp(-\rho_\mu\sigma)$ and estimated the corresponding value of r_{eff}. As can be seen from Table II, all distances were the same in our case ($r \approx 10$ m). This permits us to set up a relation of the type $N_\mu \sim E_0^\kappa$ for μ mesons incident within 24 m from the axis. Actually, it is easy to verify that

$$N_\mu = 2\pi \int_0^{24} \frac{a}{r^{0.6}}\, r\,dr = \text{const}\cdot a, \quad (5)$$

i.e., $N_\mu \sim a$. On the other hand, if the distance from the shower axis to the detector is the same for all showers and equals r_0, then $\rho_\mu(r_0) = a/r_0^{0.6}$, i.e., $\rho_\mu(r_0) \sim a$. Consequently, the dependence $\rho_\mu(r_0) \sim E_0^\kappa$ will have the same exponent as $N_\mu \sim E_0^\kappa$.

Analysis of our experiments has shown that in the energy range $1.54 \times 10^{14} \le E_0 \le 3.14 \times 10^{15}$ ev the exponent, as found by the least-squares method with allowance for the weights of the various measurements, is $\kappa = 0.42 \pm 0.14$. The results obtained are in agreement, within the limits of statistical error, with those of Vavilov[5] for μ mesons of energies ≥ 0.44 Bev and a corresponding primary-particle energy interval. This result does not contradict the value $\kappa = 0.62 \pm 0.12$, cited in reference 3 for μ mesons with energies ≥ 1 Bev.

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