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ENERGY SPECTRUM OF μ MESONS IN EXTENSIVE AIR SHOWERS

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The power exponent of the energy spectrum of μ mesons in EAS has been determined by comparing the intensity of the penetrating component of EAS at a depth of 40 m water equivalent with that at sea level. The result is $F(>E) \sim E^{-\alpha}$, where $\alpha = 0.46 \pm 0.09$.

OBSERVATIONS of EAS at a depth of 40m water equivalent (below 18 m of earth and 15 cm of lead) were initiated in our laboratory in 1960. A diagram of the arrangement (top view) is shown in Fig. 1a. Each of the areas S, S_1, or S_2 is covered by two layers of counters. A vertical section of the setup is shown in Fig. 1b. The trays S_1 and S_2 constitute part of an array used for other measurements and described in detail in [1].

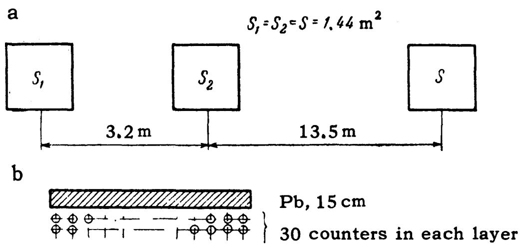

FIG. 1

Sixfold coincidences were recorded. The counting rate was $C_6 = 1.93 \pm 0.05$ hr^{-1}, as determined from the total number of showers recorded (1464). This rate was compared with the rate of EAS measured at the earth's surface under 20 cm of lead[2] in order to find the energy spectrum of μ mesons. The corresponding number of fourfold coincidences $C_4 = 0.29 \pm 0.01$ hr^{-1} refers, however, to the array shown in Fig. 2.

We can compare the rates C_6 and C_4 only after introducing the following corrections:

1. Since the effective areas S of the two arrangements differ, C_4 should be multiplied by $(S/S')^{\gamma_1}$, where γ_1 is the density spectrum exponent for showers detected under 20 cm of lead. According to our measurements carried out with the same apparatus (Fig. 2), $\gamma_1 = 1.89 \pm 0.17$.[2] Thus we have

$$C_4 (S/S')^{\gamma_1} = 5.0 \pm 1.3 \text{ hr}^{-1}.$$

2. Because of the difference in the geometry of the arrangements, we should multiple C_4 by C_3/C_4,

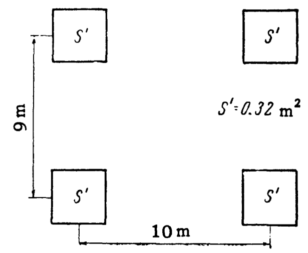

FIG. 2

where C_3 is the rate of triple coincidences at the earth's surface under 20 cm of lead for the array geometry shown in Fig. 1.

Since the difference between the lateral distributions of the electrons and μ mesons over distances of the order of several meters can introduce only a negligible error, we measured, the factor C_3/C_4 without lead (C_3'/C_4'). This applies to a change of the distance between the counters from 10 to 16.8 m. Since a distance of 16.8 m could not be realized in the underground laboratory, the measurements of the coincidence rate C_3' were carried out with the configuration of Fig. 1 at distances of 8.9 m and 13.4 m. From the two results, we determined the power exponent β of the function used for extrapolating the C_3' coincidence rate at 16.8 m. The following results were obtained:

distance between counters, m	8.9	13.4
coincidence rate, hr^{-1}	144.7±1.7	133.6±1.7

Hence $\beta = -0.20 \pm 0.04$, and for 16.8 m we found $C_3' = 128.0 \pm 3.6$ hr^{-1}.

Since the coincidence rate C_4' was found to be 79.6 ± 1.0 hr^{-1}, we have

$$C = C_4 (S/S')^{\gamma_1} (C_3'/C_4') = 8.0 \pm 2.1 \text{ hr}^{-1}.$$

Thus the rate of EAS at 40 m water equivalent is 4.1 ± 1.1 times less than at the earth's surface under 20 cm of lead.

If we denote the mean μ-meson density at the earth's surface (under 20 cm of lead) by x, and the density at the depth of 40 m water equivalent by px, we find

$$\frac{C}{C_6} = \int_0^\infty (1 - e^{-Sx})^3 x^{-\gamma_1 - 1} dx \Big/ \int_0^\infty (1 - e^{-Spx})^3 x^{-\gamma_2 - 1} dx, \quad (1)$$

where $S = 1.44\ m^2$, and γ_1 and γ_2 are the exponents of the μ-meson density spectrum under 20 cm of lead and at a depth of 40 m water equivalent respectively.

From our previous experiments[2] we have $\gamma_1 = 1.89 \pm 0.17$; according to George et al[3] $\gamma_2 = 2.2 \pm 0.2$. The latter value was found at 60 m water equivalent by means of an arrangement similar to the one used in the present experiment, but with a different effective area. From Eq. (1), it follows that

$$p = 0.47 \pm 0.07.$$

Thus, at 40 m water equivalent the flux density amounts to 50% of the μ mesons under 20 cm of lead at the earth's surface.

Assuming that the energy of the μ mesons is proportional to their residual range, and that the integral energy spectrum can be represented by a power law $E^{-\alpha}$, we can determine the exponent α. The calculations give $\alpha = 0.46 \pm 0.09$ (only statistical errors are indicated).

The results on the energy spectrum, as obtained by different investigators, are shown in the table. The value of α obtained by us agrees well with that obtained by others for the same energy range. As can be seen from the table, the exponents differ greatly for different energy ranges, i.e., the spectrum cannot be represented by a power law. No final conclusion can be drawn as to the variation of the energy spectrum with the shower size.

[1] Sándor, Somogyi, and Telbisz, KFKI Közlémenyek **6**, 117 (1958); Nuovo cimento **16**, Suppl., 209 (1960).

[2] T. Sándor and A. Somogyi, Acta Phys. Acad. Sci. Hung. (in press).

[3] George, MacAnuff, and Sturgess, Proc. Phys. Soc. **A66**, 346 (1953).

[4] Andronikashvili, Bibilashvili, Sakvarelidze, and Khushchishvili, Izv. Akad. Nauk SSSR, ser. fiz. **19**, 681 (1955), Columbia Tech. Transl. p. 619; JETP **32**, 403 (1957), Soviet Phys. JETP **5**, 341 (1957).

[5] E. L. Andronikashvili and R. E. Kazarov, Proc. Cosmic Ray Conf. IUPAP, Moscow, 1959, vol. II, p. 159.

[6] Vernov, Tulupov, Khrenov, and Khristiansen, ibid. p. 169.

[7] Higashi, Mikani, Oshiyo, Shibata, and Watanabe, ibid. p. 181.

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Experimental values of the μ-meson spectrum exponent in EAS

Reference	Depth, m w.e.	Distance from axis	Shower size, N	Energy range E, Bev	Spectrum exponent, α
[3]	12—1600			$0.4<E<400$	0.66
[4]	14—162			$0.4<E<35$	0.60 ± 0.05
[5]	13—160	~28	$1.4\cdot10^4$	$0.4<E<35$	0.54 ± 0.07
		~28	$2.9\cdot10^5$	$\{0.4<E<15$	0.34*
				$\{15<E<35$	1.25 ± 0.20
[6]	12—52	~25	$10^4<N<10^5$	$\{0.4<E<5$	0.08 ± 0.08
				$\{5<E<10$	0.33 ± 0.3
		~25	$10^5<N<6\cdot10^5$	$\{0.4<E<5$	0.1 ± 0.08
				$\{5<E<10$	0.17 ± 0.2
		~100	$10^5<N<6\cdot10^5$	$\{0.4<E<5$	0.13 ± 0.1
				$\{5<E<10$	0.45 ± 0.25
[7]	50—250			$10<E<50$	1.1 ± 0.4
Present experiment	12—50			$0.4<E<10$	0.46 ± 0.09

*This value has been computed by us from the first two points of Fig. 3 from reference 5.