ENERGY SPECTRUM OF MESONS FROM NUCLEAR DISINTEGRATIONS PRODUCED BY 9-Bev PROTONS

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Submitted to JETP editor October 28, 1959

J. Exptl. Theoret. Phys. (U.S.S.R.) **38**, 1074-1077 (April, 1960)

The energy of secondary shower particles in stars produced by 9-Bev protons in photographic emulsions was determined. The mean total energy of secondary π mesons has been found to be equal to (0.78 ± 0.10) Bev, and the mean transverse momentum equal to (0.19 ± 0.03) Bev/c. It has been found that (40 ± 5) % of the primary proton energy is spent in meson production.

In the study of the mechanism of interaction of high-energy particles and nuclei with nucleons and atomic nuclei, the spectrum of secondary relativistic particles, the majority of which are mesons, is of considerable interest. The knowledge of the energy spectrum of the mesons and, consequently, their average energy, makes it possible to compute the inelasticity coefficient and to solve the question as to whether one or another meson production theory is applicable.

For this purpose, we have determined the energy of secondary shower particles in stars produced by 9 Bev protons on emulsion nuclei. The energy was determined from multiple Coulomb scattering. Tracks (longer than 2.5 mm) for which the grain density g satisfied the condition $g \leq 1.4\, g_0$, where g_0 is the grain density in a primary proton track, were chosen for the measurements. Out of 101 stars, 62 stars were selected, in which 95 tracks suitable for scattering measurements were found.

Scattering was measured for three cells simultaneously, and the momentum of the particles was determined as in the experiment of Chasnikov et al.[1] according to the formula

$$p\beta = Kt_1^{3/2}\left(\frac{64D_1^2 + D_4^2 - 16D_2^2}{D_1^2 D_4^2 - D_2^4}\right)^{1/2}, \qquad (1)$$

where D_1, D_2, and D_4 are second differences of coordinates on the cells with the length of t_1, $2t_1$, and $4t_1$ respectively, and K is the scattering constant of the emulsion, whose numerical values for the various cell lengths are taken from the article of Fichtel and Friedländer.[2] Equation (1) was obtained under the assumption that the measured second difference of the ordinates

$$D^2 = D_{\text{coul}}^2 + n^2, \qquad (2)$$

where $n = \sqrt{D_f^2 + D_n^2}$ is the sum of the "false" scattering and of the measurement "noise." Moreover, the value of n for cell t_1 is then determined from the equation (see reference 1)

$$n_1 = (8D_1^2 - D_2^2)/\sqrt{64D_1^2 + D_4^2 - 16D_2^2}. \qquad (3)$$

The correctness of the method of measurement used was checked on the tracks of primary protons, for which the sum n_1 of "false" scattering and of "noise," as determined according to Eq. (3), was compared with the value of n determined according to Eq. (2). In the latter case, D_{Coul} corresponded to an energy of 9 Bev. It was found that, for all primary protons, both equations give the same values of n coinciding with the values of n obtained from the tracks of secondary particles.

Using the above method, which we call the "multiple-cell method," we found the energy of primary protons to be (9.0 ± 0.8) Bev. This provides the basis for considering the multiple-cell method useful for excluding the "false" scattering and "noise" in the measurements of the scattering of relativistic particles. The measurements have also shown that "false" scattering for the type of emulsion used varies with the cell length (in the range of cell lengths from 0.25 mm to 2 mm) according to the law t^x, where $x = 1$.

The particles were identified from the well-known curves of the variation of ionization with $p\beta$.[3] In all doubtful cases, the track was identified as a meson or a proton track following the method of Kalbach et al.[3] As a result of the analysis, it was found that 60 tracks belong to π mesons and 35 to protons.

The energy spectrum of investigated π mesons in the laboratory system of coordinates is shown in Fig. 1. The x axis represents the kinetic energy,

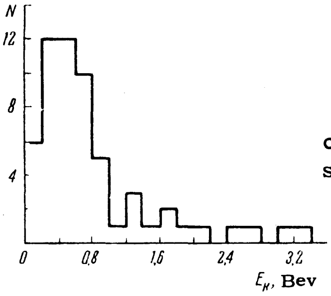

FIG. 1. Energy spectrum of π mesons in the laboratory system.

and the y axis the number of mesons per given energy interval. The mean meson kinetic energy is (0.88 ± 0.11) Bev.

The measurements of scattering and grain density along the track showed that all protons were emitted at angles $\theta \leq 25°$. In this range of angles, for particles whose momentum was measured, the ratio of the number of π mesons to the number of protons was found to be equal to 1.32. In the following discussion, it is assumed that, for angles $\theta \leq 25°$, such a ratio is correct for all shower particles, including also those which could not be identified because of the small track length. It was found that the total number of relativistic particles in that angle interval was equal to 151 for 62 stars. Hence, it follows that 65 tracks belonged to fast protons (on the average 1.05 protons per star).

The angular distribution of mesons whose momentum has been determined differs from the angular distribution of all shower particles in the same stars. From the angular distribution of all shower particles, the contribution due to protons has been excluded. It was assumed that, in each angle interval, the ratio of the number of π mesons to the number of protons is the same as for particles with measured momentum. Using this corrected angular distribution for π mesons, and the variation of the kinetic energy with the angle of emission as determined by us, it was found that the mean total energy of mesons is equal to (0.78 ± 0.10) Bev.

If we take into account that the mean number of secondary shower particles in stars selected for measurements is equal to 4.14, and that there are 1.05 protons per star, then the number of charged and neutral π mesons equals 4.6. The energy fraction of the primary protons spent for meson production is then equal to (40 ± 5)%. This value is in agreement with the results of references 4 — 7, within the limits of experimental errors.

The differential energy spectrum of mesons in the c.m.s. is shown in Fig. 2. The x axis represents the total meson energy, and the y axis the number of mesons in a given energy range. The energy is recalculated from the laboratory system to the c.m.s. under the assumption of a nucleon-nucleon interaction and of an isotropic angular distribution of produced particles in the c.m.s. The histogram shows the experimental results. The solid line represents the energy spectrum for nucleon-nucleon interactions, calculated according to the Heisenberg theory and normalized for the total number of investigated particles. The maximum in the experimentally-obtained distribution occurs for mesons with an energy of about 0.25 Bev, and the mean meson energy is equal to (0.38 ± 0.05) Bev, which is in agreement both with the results obtained for nucleon-nucleon interactions at an energy of 9 Bev,[6] and with the results of Fretter and Hansen[8] pertaining to the interaction of nucleons with light nuclei, the mean energy of the primary particles being of the order of 100 Bev. It can be seen from Fig. 2 that the experimental spectrum of mesons produced in the interaction of protons with the emulsion nuclei agrees with the theoretical spectrum calculated under the assumption of a nucleon-nucleon interaction. We find these results very interesting. They may clearly indicate the fact that almost all mesons are produced in a single nucleon-nucleon interaction. The same result is reached from an analysis of data presented in references 6 and 7, from which it follows that

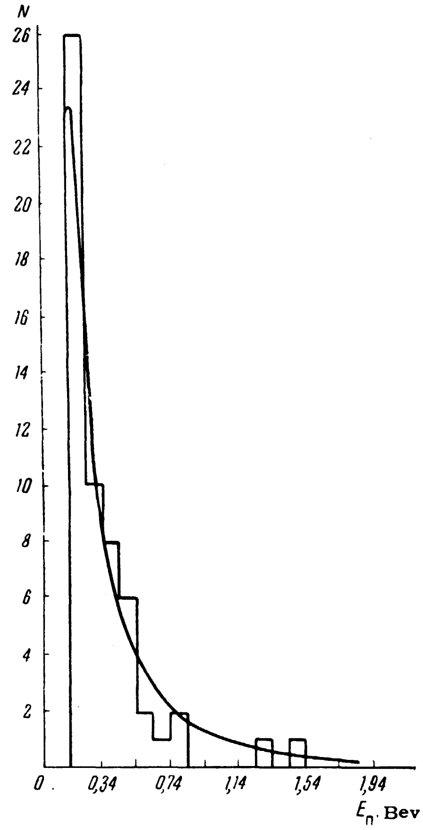

FIG. 2. Energy spectrum of π mesons in the c.m.s.

the mean number of shower particles n_s is almost independent of the size of the target nucleus. This problem will be discussed by us in greater detail in a future article.

The transverse momentum distribution of the mesons is shown in Fig. 3. The maximum of this distribution lies inside the range 0.11 to 0.16 Bev/c,

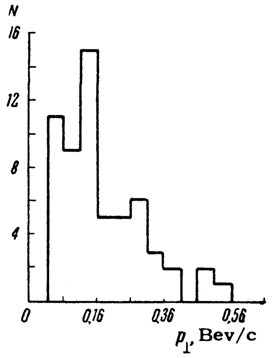

FIG. 3. Transverse momentum distribution of mesons.

which corresponds to the value of $m_\pi c$. The mean transverse momentum of mesons whose scattering has been measured is equal to (0.19 ± 0.03) Bev/c, i.e., is considerably smaller than the value obtained by Barashenkov et al.[7]

It should be noted that the conclusion about the cascade character of the nucleon-nucleus interaction[7] is in agreement with the results obtained by us earlier[9] in the analysis of the energy spectrum of protons with ionization from 1.4 g_0 to 6.8 g_0 from stars produced by cosmic-ray particles with a mean energy on the order of 10 Bev. The development of the nucleon cascade inside the nucleus does not exclude the possibility that all mesons are produced in a single interaction between the incident nucleon and one of the nucleons of the nucleus, with the ensuing collisions between nucleons and mesons possibly being elastic.

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Translated by H. Kasha
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