STUDY OF THE FINE STRUCTURE OF THE γ-RAY ENERGY SPECTRUM PRODUCED BY 18.7-BeV PROTONS IN PHOTOGRAPHIC EMULSION NUCLEI

G. B. ZHDANOV, M. I. TRET'YAKOVA, and M. N. SHCHERBAKOVA

P. N. Lebedev Physics Institute, Academy of Sciences, U.S.S.R.

Submitted to JETP editor May 18, 1964

J. Exptl. Theoret. Phys. (U.S.S.R.) **47**, 1664-1667 (November, 1964)

The fine structure of the γ-ray energy spectrum produced in a photographic emulsion by 19.6 BeV/c protons has been studied in the energy range 140—950 MeV. 222 electron-positron pairs were analyzed. We have not observed any statistically certain peaks which could be ascribed to the intense two-photon decay of η mesons, as have been observed in experiments [1-3] with lower energy primary particles.

SEVERAL workers [1-3] have obtained an indication that the formation and subsequent two-photon decay of η mesons plays an important role in the production of γ rays in nuclear interactions with energies of several BeV.

King [1] used photographic emulsions to study the energy spectrum of photons created by 3.5 BeV π^- mesons. The spectrum shape for emission angles $\theta > 10°$ is such that one suspects the existence of γ-ray sources in addition to π^0-meson decay. Chretien et al [2] used a bubble chamber to study the distribution of the angle θ_{12} between two γ rays produced by π^- mesons with a momentum of about 1 BeV/c in the reaction $\pi^- + p \rightarrow X_0 + n$. In addition to the main peak near $\theta_{12} = 25°$ (corresponding to an X_0 particle mass of 144 ± 16 MeV), they observed a small but clearly expressed additional peak at $\theta_{12} = 100°$ which corresponds to the two-photon decay of X_0 particles with a mass 545 $\pm$ 30 MeV.

Finally, a group under Podgoretskiĭ, [3] using a bubble chamber, studied the spectrum of γ rays produced by 7-BeV π^- mesons (the results obtained by these authors will be discussed below).

We have attempted to observe the additional γ-ray generation process by analyzing the spectrum of electron pairs in an Ilford G5 photographic emulsion irradiated by a 19.6-BeV/c proton beam. We studied the energy interval 140—950 MeV. With this purpose we have made a preliminary selection of roughly 1500 electron pairs with electron-positron separation angles in the range $\alpha = 3 \times 10^{-3}$ to 2×10^{-2}. The energy of each pair was determined, as a rule, with an error of about 15% from multiple scattering measurements in a single emulsion layer, using track lengths averaging about 7 mm.

We used altogether four emulsion layers, which differed only slightly in the level of spurious scattering. The principal method of taking into account the spurious scattering was to introduce corrections by means of averaged curves of the measured energy value of the particle ϵ as a function of the length of the measurement cell t. We can see from Fig. 1 that over the entire relevant single-particle energy range up to 400 MeV these corrections reach 45% for a 100-μ cell and do not exceed 20% for a 200-μ cell. Therefore a 200-μ cell was considered as the basic measurement cell; it was used in roughly 80% of the cases for 185—315 MeV particles and in 70% of the cases for 320—550 MeV particles.

As an additional method of determining the effect of spurious scattering we used the quantity ρ, the ratio of the mean values of the third and the second differences of the y-coordinate for a given

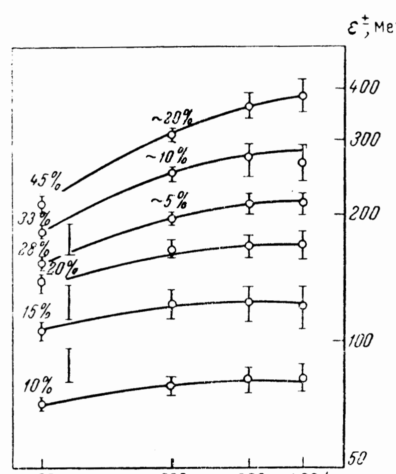

FIG. 1. Average results of scattering measurements on electron and positron tracks for different lengths of the measurement cell. Near the appropriate experimental points are given mean values of the correction for spurious scattering.

t	$\varepsilon^{\pm} = 150 - 200$ MeV		$\varepsilon^{\pm} = 300 - 400$ MeV	
	$\bar{\rho}$	$(D\rho)^{1/2}$	$\bar{\rho}$	$(D\rho)^{1/2}$
100 μ	1.47	0.09 *	1.64	0.10 *
200 μ	1.31	0.15 **	1.35	0.16 **

*Dispersion of ρ values determined from 70-80 cells.
**Dispersion of ρ values determined from 35-40 cells.

track. Here we made use of the fact that the value of ρ should be $\sqrt{1.5}$ for pure Coulomb scattering and $\sqrt{3}$ for spurious scattering. The table lists values averaged over many tracks (at least 400 cells in each case) for different cell lengths t and different particle energies. An examination showed that introducing corrections by the first and second methods gives results which differ by not more than 10% in 90% of the cases for a 200-μ cell, although sometimes a difference reaches 13–15%.

An important question in relation to this method is to what degree the determination of the divergence angle α of the electron-positron pair can serve as a measure of its energy. Podgoretskiĭ et al [4] converted the average value $\overline{\alpha^{-1}}$ to the corresponding average energy of a group of pairs $\overline{E(\alpha)}$ by using the theoretical formula

$$\overline{E(\alpha)} = C\overline{\alpha^{-1}}$$

with a coefficient C = 2.9 MeV[1)]. For the energy region 200–400 MeV which interests us in this case, we selected 90 electron pairs, first by their angles α, having determined their mean true value of photon energy $h\nu_{\text{true}}$, and second by their value of $h\nu_{\text{true}}$, having determined their mean value of the coefficient C. If we exclude from consideration in both cases pairs with sharply unequal energy partition between the components ($E_1/E_2 > 5$), then in the first case we obtain a coefficient $C_1 = 2.2$ MeV, and in the second case $C_2 = 1.5$ MeV.

The distribution shown in Fig. 2 of individual values of "instrumental" energy $E(\alpha)$ for a given true energy $h\nu_{\text{true}}$, and on the other hand the distribution in $h\nu_{\text{true}}$ for given α and C, allow us to judge with what accuracy relation (1) is fulfilled for an actual group of selected events and for different selection methods.

After carrying out the necessary measurements and making corrections for spurious scattering, we

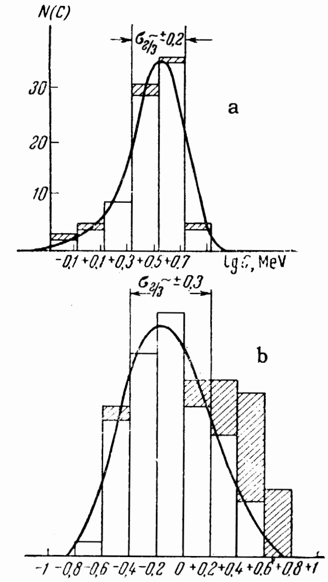

FIG. 2. a) Distribution of "instrumental" energy values $E(\alpha)$ determined from the opening angle of a pair for a fixed value of true γ-ray energy $h\nu_{\text{true}}$; b) distribution of values of $h\nu_{\text{true}}$ for a fixed value of $E(\alpha)$.

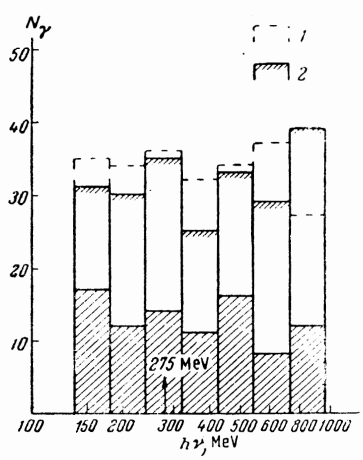

FIG. 3. γ-ray energy spectra: 1) Before correction for spurious scattering; 2) after correction. The cross-hatched part of the spectrum (with corrections) refers to γ-ray emission angles of 10° and greater with respect to the primary beam direction.

were left with 222 pairs in the energy interval 140–950 MeV whose energy was measured with an accuracy of 20% or better. Since our problem did not involve determination of the exact shape of the energy spectrum of γ rays, but only observation of possible fine structure, we refrained from introducing energy-dependent corrections to the electron pair counting efficiency[2)], since all these cor-

1)The conversion coefficient C′ directly obtained by Podgoretskiĭ et al [4] was 4.15 MeV; however, this referred to the spatial angles of divergence of the particles in the pair. In converting from the spatial angles to the plane angles, we introduced a factor $1/\sqrt{2}$.

2)In calculating such corrections it would be necessary to take into account at least three factors: a) geometrical factors connected with the dependence of the photon angular distribution on E_γ; b) corrections to the yield of particles from the emulsion layer due to scattering; c) the effect of the preliminary selection in angle α.

rections should be expressed by smooth functions of the photon energy E_γ. It is appropriate to plot the experimental data on a logarithmic energy scale, since the spectrum obtained (without corrections) is rather close to the bremsstrahlung spectrum

$$N(E_\gamma)\,dE_\gamma \sim d(\log E_\gamma),$$

and in addition the error in determining the energy E_γ has a slight logarithmic energy dependence, rather than a linear one.

The γ-ray energy spectrum obtained is shown in Fig. 3; the spectrum uncorrected for spurious scattering is also shown for comparison. It is evident that within the energy intervals selected, which correspond to a 30% increase, small peaks in the number of pairs are observed not only near $E_{\gamma_1} = 275$ MeV (half the rest mass of the η meson) but also near $E_{\gamma_2} = 500$ MeV; however, in both cases the peak hardly exceeds one standard deviation and therefore has practically no significance. Thus, the indication previously obtained with somewhat better statistics by Lyubimov et al [3] of the existence of two-photon decays under the conditions of our experiment, does not appear here.[3)]

[3)]Recently it came to our attention that a continuation of the work of Lyubimov et al [4] also led the authors to a negative result; [5] they obtain an upper limit of 0.5 mb for the cross section for production of η mesons.

The relative height of the 500 MeV peak becomes somewhat larger (reaching two standard deviations) if we select only γ rays whose direction is at least 10° from the primary proton beam. However, the insignificant statistics (a total of 16 events in the region of this peak) prevent us, even in this case, from having adequate confidence in the real existence of the additional mechanism of γ-ray production.

The authors wish to thank W. O. Lock and J. Combe for the irradiated emulsions obtained from CERN, and M. I. Podgoretskiĭ for discussion of our results.

[1] D. T. King, Bull. Am. Phys. Soc. **6**, 39 (1961).

[2] Chrétien, Bulos, Crouch, et al, Phys. Rev. Letters **9**, 127 (1962).

[3] Lyubimov, Tsun, Podgoretskiĭ, Portnova, Strel'tsov, and Trka, JETP **44**, 760 (1963), Soviet Phys. JETP **17**, 513 (1963).

[4] Bayatyan, Gramenitskiĭ, Nomofilov, Podgoretskiĭ, and Skrzypczak, JETP **36**, 690 (1959), Soviet Phys. JETP **9**, 483 (1959).

[5] Lyubimov, Tsun, Portnova, and Strel'tsov, JINR preprint R-1629, 1964.

Translated by C. S. Robinson
235