PROPERTIES OF π^0 MESONS PRODUCED WITH STRANGE PARTICLES IN π^--p AND π^--C INTERACTIONS

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This investigation was performed with a 24-liter propane bubble chamber [1] and is a continuation of our previous work on the production of strange particles by 7—8-BeV π^- mesons on hydrogen and carbon. [2-5] The properties of π^0 mesons inferred from the γ quanta accompanying Λ and K^0 production are given, and are compared with the properties of π^+ and π^- mesons emitted in Λ and K^0 production processes. The possibility of a resonance with radiative decay is noted.

SELECTION OF EVENTS

THE experimental procedure, the characteristics of the beam, the procedure used in scanning and analyzing the photographs, and the criteria used in selecting π^--p and π^--C events have been described in [2,6]. From among the events used in [5] we selected 188 instances in which Λ and K^0 production are accompanied by at least one electron-positron pair from γ conversion (Table I).

The assignment of a γ quantum to a given star was based on its direction from the point of collision. Events were considered to be collinear when the deviation from collinearity did not exceed 1.5°.

The probability of γ conversion into an electron-positron pair in the $55\times28\times14$-cm chamber was very small because of the 1.1-m radiation length in propane. The statistical weight of each γ quantum was calculated from the formula

$$W_i = \{1 - \exp[-L_\gamma\mu(E_\gamma)]\}^{-1},$$

where L_γ is the potential range of a γ quantum in radiation units,[1)] and $\mu(E_\gamma)$ is the probability of e^+e^- pair production in the radiation length.

The mean γ registration efficiency determined from the relation $\overline{P}_i = 1/\overline{W}_l$ was 0.09 ± 0.01 for our chamber. In calculating the total number of γ quanta we introduced corrections for 1) the loss of γ quanta emitted at large azimuthal angles and 2) asymmetry of the incident beam relative to the longitudinal axis of the chamber. The total correction factor was 1.51 ± 0.40. We studied π^0 mesons from the reactions

$$\pi^- + p \to \Lambda(\Sigma^0) + K^0(K^+) + l\pi^+ + m\pi^- + n\pi^0,$$

$$\pi^- + p \to K^0(\overline{K}^0) + \overline{K}^0(K^\mp) + l\pi^+ + m\pi^- + n\pi^0 + N.$$

The production of π^0 mesons on carbon nuclei proceeds via the same channels. It is known that the great majority of π^0 mesons decay according to

$$\pi^0 \to \gamma + \gamma.$$

All events involving γ quanta were divided into two groups according to the types of accompanying strange particles:

$$[\Lambda(\Sigma^0)\gamma]\,\pi^-p \text{ and } [K^0(\overline{K}^0)\gamma]\,\pi^-p$$

for π^--p interactions and

$$[\Lambda(\Sigma^0)\gamma]\,\pi^-C \text{ and } [K^0(\overline{K}^0)\gamma]\,\pi^-C$$

for interactions on carbon. Both groups included γ quanta registered with a ΛK^0 pair.

ANALYSIS OF EXPERIMENTAL DATA

1. Average number of π^0 mesons. If it is assumed that all γ quanta result from π^0 decay, the average number of π^0 mesons can be calculated from

$$\bar{n}_{\pi^0} = 1.51\sum_i W_i/2N,$$

where W_i is the statistical weight of a γ quantum, 1.51 is a geometric correction, and N is the total

1)The potential range is the distance from the production point to the boundary of the effective region of the chamber in which γ conversion can be observed. The effective region for γ registration is the same as for Λ and K^0 registration.

Table I. Distribution of events in which strange particles and γ quanta are produced

Interaction	Types of events									
	$\Lambda+\gamma$	$\Lambda+2\gamma$	$\Lambda+3\gamma$	$K^0+\gamma$	$K^0+2\gamma$	$K^0+3\gamma$	$K^0\bar{K}^0+\gamma$	$\Lambda K^0+\gamma$	$\Lambda K^0+2\gamma$	Total
π^-+p	52	6	—	46	2	0	5	7	3	121
π^-+C	20	5	1	24	4	1	0	9	3	67

Table II. Average number of π^0 mesons for stars with different charged particle multiplicities

n_{π^0}	n_s		
	0	2	4 и 6
$\bar{n}(\Lambda\gamma)$	1.56±0.40	1.37±0.20	0.80±0.20
$\bar{n}(K^0\gamma)$	1.42±0.39	0.88±0.15	0.68±0.17

Note. The first line represents the average number of π^0 mesons accompanying Λ production; the second line represents the average number accompanying K^0 production

Table III. Average numbers of π^0 mesons produced in different reactions.

Type of interaction	Reactions with strange-particle production				Without strange particles	
	$[\Lambda(\Sigma^0)\gamma]\ \pi^-p$	$[K^0(\bar{K}^0)\gamma]\ \pi^-p$	$[\Lambda(\Sigma^0)\gamma]\ \pi^-C$	$[K^0(\bar{K}^0)\gamma]\ \pi^-C$	$[N_\gamma]\ \pi^-p$	$[N_\gamma]\ \pi^-C$
$\bar{n}_{\pi^0}$	1.23±0.17	0.92±0.13	1.24±0.20	1.40±0.29	1.48±0.18	1.50±0.32

number of events involving Λ or K^0 production (with or without γ quanta). The formula was used to calculate the average number of π^0 mesons accompanying Λ and K^0 production in π^--p interactions for stars with 0, 2, and 4 or 6 charged particles (Table II). The average number of π^0 mesons decreases with increasing charged particle multiplicity, although the errors are quite large.

In Table III the average number of π^0 mesons accompanying strange particles is compared with the average number produced without strange particles.[8] The average number of π^0 mesons is seen to depend slightly on the existence and types of strange particles, as well as on the target in which the interactions occur.

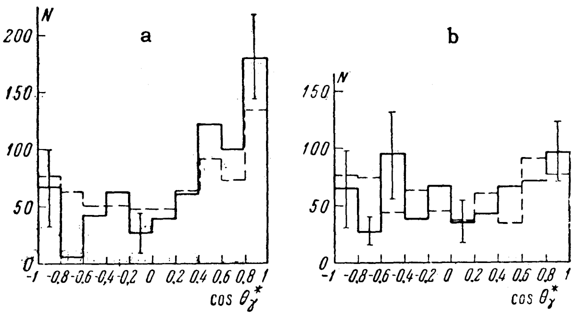

FIG. 1. Angular distributions of gamma quanta from π^-–p interactions in the pion-nucleon c.m.s. and normalized π^-– meson distributions (dashed lines) for: a–$[\Lambda(\Sigma^0)\gamma]\ \pi^-p$, and b–$[K^0\bar{K}^0)\gamma]\ \pi^-p$.

2. Angular distributions of γ quanta. Figure 1 shows the angular distributions of γ quanta in the pion-nucleon c.m.s. for $[\Lambda(\Sigma^0)\gamma]\pi^-p$, and $[K^0(\bar{K}^0)\gamma]\pi^-p$, denoted by a and b, respectively. The normalized π^- distributions are represented by the dashed lines. The angular distributions of γ quanta and π^- mesons are seen to be practically identical for our statistics.[2)] The angular distribution of γ quanta from $[K^0(\bar{K}^0)\gamma]\pi^-p$ is isotropic, while that from $[\Lambda(\Sigma^0)\gamma]\pi^-p$ is peaked forward like the distribution of negative pions from the same interactions.

Figure 2 shows the angular distributions of γ

[2)]The angular distribution of γ quanta reflects that of π^0 mesons with some spreading. However, for our π energies there is little change in the distribution, since the angle between the π^0 and γ directions in ~80% of the events lies within our selected interval $\Delta(\cos\theta) = 0.2$.

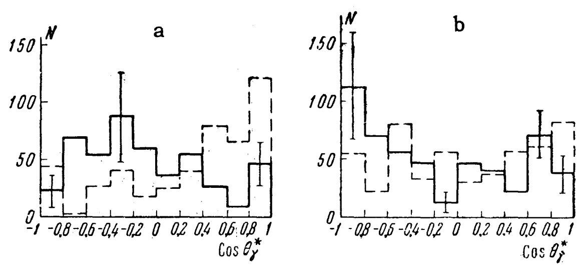

FIG. 2. Angular distributions of γ quanta from π^--C interactions (continuous lines) and from π^--p interactions (dashed lines) normalized to the same area. a – distributions for $[\Lambda(\Sigma^0)\gamma]\pi^-$C; b – for $[K^0(\bar{K}^0)\gamma]\pi^-$C.

quanta from $[\Lambda(\Sigma^0)\gamma]\pi^-$C and $[K^0(\bar{K}^0)\gamma]\pi^-$C. For comparison, the figure includes dashed lines representing the analogous distributions for reactions with protons, normalized to the same area. Both distributions are given in the pion-nucleon c.m.s. Differences are observed, especially for the distribution of γ quanta produced together with Λ hyperons on carbon and on hydrogen. The distributions for interactions with carbon are more isotropic.

3. Average number of π^0 mesons. The average energy of π^0 mesons was assumed to be twice the average energy of γ quanta.[9] The average energy of π^0 mesons produced with strange particles was compared with the average energy of charged pions, and also with the average energy of pions produced without strange particles.[8] Table IV shows the close values of the average energies of all pions produced with strange particles when multiplicity is disregarded. However, the average energy of π^- mesons produced with strange particles is smaller than that without strange particles.

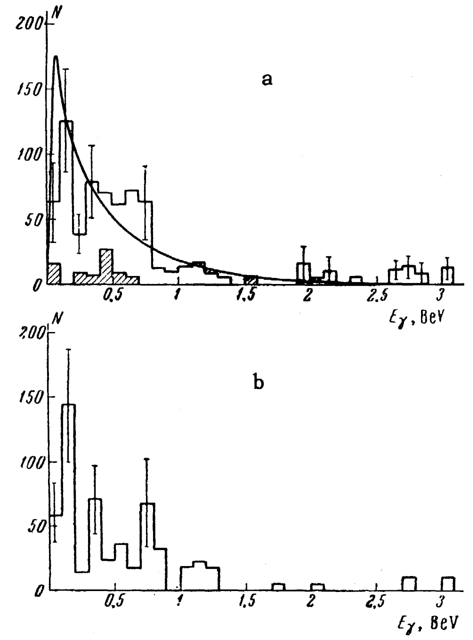

FIG. 3. Energy distributions of γ quanta for a – $[\Lambda(\Sigma^0)\gamma]\pi^-$p and b – $[K^0(\bar{K}^0)\gamma]\pi^-$p. The smooth curve in a represents the $\pi^-(\pi^0)$ spectrum converted into the γ spectrum normalized to the same area. The cross-hatched γ spectrum pertains to the reaction $\rho^0(\omega^0) \to \pi^+ + \pi^- + \gamma$.

4. Energy spectrum of γ quanta in laboratory system. The experimental energy spectrum of γ quanta from interactions leading to Λ production is shown in Fig. 3a, and that with K^0 production in Fig. 3b. As already mentioned, it is possible that not all γ quanta result from π^0 decay. In order to distinguish the part of the γ spectrum pertaining to π^0 mesons we assume that the π^0 momentum distribution coincides with the π^- momentum

Table IV. Average energy of π mesons for different reactions and pion multiplicities

Reaction	Average π energy, BeV	Multiplicity			Disregarding multiplicity
		0	2	4–6	
$[\Lambda(\Sigma^0)\gamma]\pi^-p$	E_{π^0}	1.38±0.19	1.34±0.14	1.54±0.32	1.38±0.12
	E_{π^-}	—	1.56±0.10	0.99±0.06	1.28±0.06
	E_{π^+}	—	1.73±0.10	1.25±0.08	1.49±0.06
$[K^0(\bar{K}^0)\gamma]\pi^-p$	E_{π^0}	1.66±0.30	0.97±0.16	1.07±0.20	1.10±0.25
	E_{π^-}	—	1.46±0.08	1.05±0.05	1.24±0.05
	E_{π^+}	—	1.04±0.05	1.13±0.05	1.08±0.04
$(N\gamma)\pi^-p$ [8]	E_{π^0}	2.04±0.12	1.29±0.30	0.77±0.12	1.08±0.08
	E_{π^-}	—	2.60±0.19	1.40±0.09	1.64±0.08
	E_{π^+}	—	1.23±0.07	1.23±0.07	1.23±0.06

*At our energies a positive particle could not be identified reliably as either π^+, K^+, or p. Positive-particle energies were calculated in all events from the average momentum of all positive particles and the pion mass.

distribution for the same reactions. The π^- momentum spectrum is given in [10].

It is known that the relation between γ energy and π^0 velocity β is given by

$$E_\gamma = \frac{m_{\pi^0}}{2(1-\beta\cos\theta)}\sqrt{1-\beta^2},$$

where m_{π^0} is the π^0 mass and θ is the angle between the π^0 meson and γ quantum. This relation can be used to determine the maximum ($E_{\gamma max}$) and minimum ($E_{\gamma min}$) energies arising from a π^0 meson with the velocity β:

$$E_{\gamma max} = \frac{1}{2}Bm_{\pi^0}(1+\beta), \quad E_{\gamma min} = \frac{1}{2}Bm_{\pi^0}(1-\beta),$$

where

$$B = 1/\sqrt{1-\beta^2}.$$

It has been shown in [11] that for constant β the γ distribution is uniform between $E_{\gamma min}$ and $E_{\gamma max}$; therefore each energy interval in the π^- distribution is converted in the γ distribution into a rectangle having the width $E_{\gamma max} - E_{\gamma min}$ and height determined from the equality of the areas. The normalized converted spectrum of γ quanta from $\pi^0(\pi^-)$ mesons is represented with the experimental γ spectrum by a smooth curve drawn through the midpoints of the intervals.

Figure 3 shows that the experimental γ energy distribution in the laboratory system differs from the converted spectrum (of γ quanta from π^0 decay) in the range 300—700 MeV. We do not believe that this difference can be accounted for by statistical fluctuations alone, but that it results most probably from the existence of γ sources other than π^0 mesons.3) The nonmonotonic character of the spectrum cannot be accounted for by γ quanta from the reaction $\Sigma^0 \to \Lambda + \gamma$ because, as shown in [8], the same nonmonotonic result is also observed in ordinary π production processes.

5. Search for resonances with radiative decay. The effective-mass distribution for $M(\pi^+ + \pi^- + \gamma)$ exhibits a peak at about 760 MeV (Fig. 4). Therefore our result indicates the possibility of ω^0 or ρ^0 decay via the channel $\omega^0(\rho^0) \to \pi^+ + \pi^- + \gamma$.[12]

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3)The γ energy spectrum should have a single maximum at $E = \frac{1}{2}m_{\pi^0}$ if π^0 mesons are the only source of γ quanta.

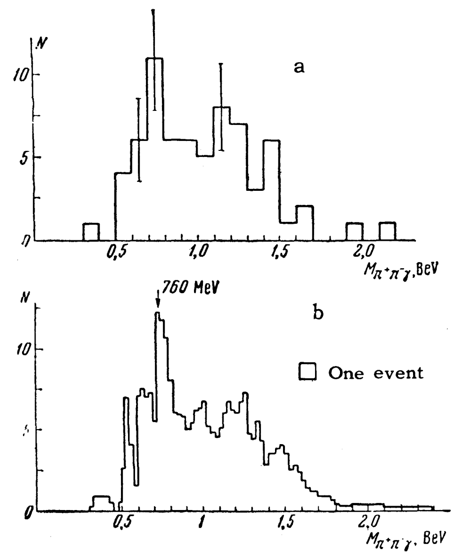

FIG. 4. a – histogram; b – ideogram of effective masses for $\pi^+\pi^-\gamma$ combinations from two-prong stars with a Λ hyperon and γ quantum.

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