Search for new short-lived particles in collisions between 60 GeV/c π^- mesons and emulsion nuclei

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(Submitted July 28, 1977)
Pis'ma Zh. Eksp. Teor. Fiz. **26**, No. 5, 399–403 (5 September 1977)

We investigated the vicinities of ~ 10000 stars from interactions of π^- mesons with emulsion nuclei at a momentum 60 GeV/c. We found one event that can be interpreted as a leptonic decay of a new particle. Under resonable assumptions concerning the decay mode, the effective mass of the particle is $\sim$ 2.4 GeV and its lifetime is $\sim 10^{-14}$ sec.

PACS numbers: 13.85.—t, 14.40.Pe, 13.20.Jf

Observation of X particles with mass $M = 1.5$—3.5 GeV and lifetime $\tau \sim 10^{-14}$ sec,[1] the observation of resonances called J or ψ particles,[2] and the subsequent development of the ideas concerning charmed particles has uncovered great prospects for the search for new particles. Considerable efforts were made by using emulsions as well as other methods.[4–11] The possibility of searching for new particles with lifetimes $\sim 10^{-15}$—10^{-12} sec was considered by one of us in 1967.[3]

The use of emulsions is also of interest in connection with a study of the "direct lepton production" process in hadron—hadron and hadron-nuclei collisions. The customarily employed electronic procedure does not have a sufficient spatial resolution to distinguish cases of "direct lepton production" in the collision process itself from the decays of the new short-lived particles. Emulsions having a spatial resolution of several microns can yield quite substantial additional data.

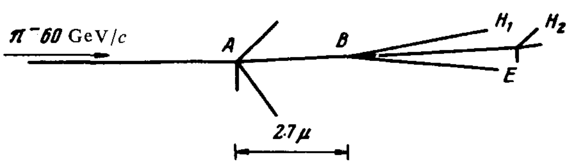

FIG. 1.

In our experiment, a BR-2 emulsion stack was bombarded with a beam of 60-GeV/*c* π^- mesons from the Serpukhov accelerator at an intensity $\sim 10^5$ particles/cm^2. Stars due to the interaction of the primary π^- mesons were searched for with a microscope of small magnification (7×10). The positions of the obtained stars were marked on a special blank that duplicated the coordinate grid on the emulsion layer.

After scanning ~ 0.3 cm^2, the observer searched for secondary interactions or decays near the obtained stars at a larger (15×60) magnification. The emulsion volume scanned in this case near each star was a cone with apex angle $\sim 45°$ directed forward relative to the beam and extending up to 100 μm from the center of the star.

The main attributes of generation and decay of a new particle was the presence of a high-energy electron among the decay products. One such case was found. The event constituted topologically the formation of a second star at a distance 27 μm from the primary star. The secondary star, at first glance, consisted of five relativistic-particle tracks converging to a single point. The row of grains between the primary and secondary stars indicated the presence of relativistic tracks there. Measurements of the geometry of the event and a thorough reduction has established that two tracks of the "secondary star" belong in fact to the primary star, and the scheme of event takes the form shown in Fig. 1. The primary star "*A*" has a short black prong, a gray prong, and six relativistic particles. One of these particles, at a distance 27 μm from the center of the star at the point "*B*" initiates three secondary relativistic tracks. The space angle of the track *AB* was measured relative to the direction of the primary π^- mesons, and the space angles of the tracks BH_1, BH_2, and *BE* were measured relative to the *AB* direction. The tracks BH_1,

TABLE I.

Track	Space angle, $\theta°$	Azimuthal angle $\psi°$	$p\beta$ GeV/*c*	$p_\perp$ GeV/*c*	Relative ionization, *I*	Track length, cm	Note
BA	3.3	333	–	–	–	$27\cdot10^{-4}$	–
BH_1	1.6	306	2.8 ±0.3	0.08	0.95 ±0.05	15	–
BH_2	6.0	90	4.3 ±0.4	0.45	1.0 ± 0.06	9	produces a star
BE	1.9	219	1.2 ±0.2	0.04	1.0 ±0.05	7	is stopped

TABLE II.

№	Background source	Probability
	Decays	
1	$\pi^{\pm} \to e^{\pm}\nu(\nu)$	$\sim 3.6 \cdot 10^{-6}$
	$K^{\pm} \to e^{\pm}\pi^{0}\nu(\bar{\nu})$	$\sim 4 \cdot 10^{-5}$
	$\Sigma^{+} \to e^{+}\Lambda\nu$	$\sim 7 \cdot 10^{-7}$
	$\Sigma^{+} \to e^{+}n\nu$	$\sim 10^{-7}$
	$\Sigma^{-} \to e^{-}n\bar{\nu}$	$\sim 10^{-5}$
	$\Xi^{-} \to e^{-}\Lambda\bar{\nu}$	$\sim 10^{-5}$
2	Asymmetrical Dalitz pair	$\sim 5 \cdot 10^{-5}$
3	Annihilation of e^{+} from a Dalitz pair	$\sim 3 \cdot 10^{-7}$
4	Compton electron	$\sim 3 \cdot 10^{-6}$
5	δ electron	kinematically excluded

BH_2, and BE were continued respectively to the emergence from the stack, to the interaction, or to the stopping point. The measured characteristics of the particles are listed in Table I. The BH_1 track is a typical track of a fast hadron that covers a distance ~ 15 cm prior to leaving the emulsion without a change in momentum or ionization within the limits of the measurement errors. The track BH_2 obviously belongs to the hadron, since it forms a multiprong star after 9 cm of path. The behavior of the track BH is typical of that of a fast electron. The quantity $p\beta$ changes noticeably over 7 cm of track being 1.2 ± 0.2 GeV/c on the first three centimeters, 0.5 ± 1 on the next two centimeters, and 0.2 ± 0.06 on the last two centimeters. The ionization in all three sections where $p\beta$ was measured remains unchanged within the limits of the measurement errors, with an average value 1.0 ± 0.05 relative to the ionization on the tracks of the primary π^- mesons. At the end of the path, the particle with track BE undergoes scattering through an angle $\sim 10°$, $p\beta$ decreases to several MeV, and the particle is strongly scattered.

All the tracks of the primary star, and also of its vicinity in the neighboring layers of the emulsion, were examined for the purpose of observing the track of an electron or of some event correlated with the primary interaction. None were observed.

From the point of view of the secondary particles—two hadrons and an electron—the obtained event does not fit any known strange particle: the probability of observing a K meson or hyperon decaying in this manner is less than 10^{-6} in our case. If we assume that the observed event is an elastic interaction of a secondary fast particle, then we must find an explanation for the presence of the electron track BE in the secondary star.

An electron can be produced at the point B as a member of a Dalitz pair (decay of a π^0 meson produced at the point B into $\gamma e^+ e^-$). The second member of the pair can be taken to be the track BH_1. This however, is more readily a hadron track, since the probability that an electron can traverse an emulsion thickness of 15 cm without change of momentum is $< 7\times10^{-3}$. If we assume nevertheless that the track BH_1 belongs to an electron and calculate the probability of observing in our experiment a Dalitz pair with such an electron, we obtain a value $\sim 10^{-3}$ per 10 000 stars. It occurs sometimes that the second member of the Dalitz pair does not leave a visible track in the emulsion. In practice this can take place in two cases: when an asymmetrical Dalitz pair is produced and one of the components has too low an energy ($\lesssim$ 100 keV) to be registered in the emulsion, or when the second member is a positron that undergoes annihilation at a short distance from the point B.

The probability of observing such events is small. The corresponding values are given in Table II, which lists also the probabilities of other more or less significant background sources: the decay of an unstable particle emitted from the point B at a short distance (~ 3 μm) from the center of the secondary star; production of a Compton electron by a γ photon from the decay of the π^0 meson from the primary or secondary star. As seen from Table II, these are very small.

The generation of a high-energy δ electron by the particle to which the track AB belongs or by one of the secondary particles from the star B is kinematically excluded.

It is thus difficult to attribute the observed events to decays or to interactions. It can be assumed that we are dealing with a leptonic decay of a new short-lived particle, say a charmed one

$$M_c \to e + \text{hadrons} + \nu_e.$$

The existence of at least one neutral particle follows from the balance of the transverse momenta of the secondary charged particles $\Sigma \mathbf{P}_L = 0.4 \pm 0.1$ GeV/c.

Assuming that the tracks BH_1 and BH_2 belong to pions or kaons, and assuming an isotropic distribution of the decayed neutrinos, we obtain for the average effective mass of the new particle $M_c \sim 2.4$ GeV. The corresponding lifetime of the particle is $\tau_c \sim 10^{-14}$ sec.

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