Observation of decays of short-lived particles in an emulsion exposed to 400-GeV/*c* protons

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(Submitted 29 August 1978)
Pis'ma Zh. Eksp. Teor. Fiz. **28**, No. 7, 490–494 (5 October 1978)

The nine events of short-lived particle decay observed in an emulsion bombarded with 400-GeV/*c* protons are interpreted as decays of charmed particles (mainly baryons). An estimate of the lifetime yielded a value 1.2×10^{-14} sec. The cross section for the production of charmed particles was found to be ~ 100 μb/nucleon.

PACS numbers: 13.85.Hd, 14.20.Gk

1. The results of a number of recent investigations have reinforced the interest in the problem of production of charmed particles in hadron collisions. On the one hand, attempts to register their production in hadron collisions by electron methods have so far met no success.[1-3] On the other hand, the results of experiments on dumping a beam of protons with energy 400 GeV on a target, which led to observation of direct neutrinos,[4-6] have indicated that the cross section σ_N^{ch}, is quite appreciable and lies in the range 100–400 μb.[1)]

It is appropriate to recall in this connection that for many years individual anomalous events were observed in emulsions bombarded by beams of high-energy particles and were interpreted as production of charmed particles.[7,8] In their totality, these data attested to an appreciable value of σ_N^{ch} (at the 100 μb level). The greatly differing conclusion ($\sigma_N^{ch} < 1.5$ μb) obtained with emulsions in Ref. 11, as far as we can judge, is due to the use for the events of a selection criterion that did not enable the authors to note the formation of charmed particles.

In this paper we report results of a systematic search of events in which charmed particles are produced and decay in emulsion bombarded by 400-GeV/*c* momentum. This study was undertaken more than a year ago and is based on the use of a new procedure.[2)]

2. The experiments were performed on type BR-2 nuclear emulsions measuring 10×20 cm with emulsion layer thickness ~ 600 μm. The irradiation was parallel to the emulsion plane in the FNAL (Batavia, USA) accelerator.

Scanning of the emulsion revealed 1120 primary proton interactions (stars). To observe the case of decay of short-lived particles, we investigated the forward peak of each star up to distances $\Delta X = 1000$ μm (along the primary proton beam) and $\Delta Y = \pm 60$ μm, $\Delta Z = \pm 50$ μm (for the two directions perpendicular to the x axis). The secondary star was classified as a possible decay under the following conditions:

1) There were no black and gray tracks, recoil nuclei, or β electrons.

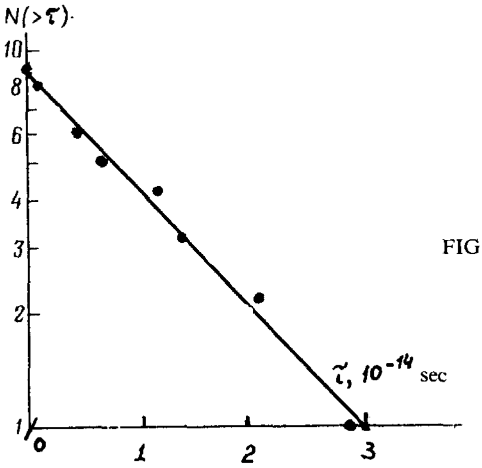

FIG. 1. Integral lifetime spectrum of short-lived particles.

2) The number of relativistic particles n_s was even or odd, depending on the charge of the decaying particle (0, $\pm$ 1e).

For all the cases of interest, we measured the emission angles of the produced particles, their momenta, and their characteristic ionization. The momenta were measured by determining the multiple Coulomb scatterings, with an error of 15–20%.

3. An analysis of the vicinities of 1120 primary stars has revealed 14 secondary stars with black and gray tracks, approximately the expected number. In addition, we obtained 21 secondary stars of the $0+0+n_s$ type, whereas the expected number of such stars should have been 10% of the number of stars with black and gray tracks, i.e., one or two. With further analysis of the "pure" secondary stars it turned out that:

Seven of them were connected with acts of e^+e^- pair production with rather large apex angle (0.5–1.3°).

Two stars were the result of the random landing of the vertex of an e^+e^- pair in the immediate vicinity of the charge-particle track.

One star was due to production of an e^+e^- pair by a charged hadron in the field of the emulsion nucleus.

One star is more readily a normal secondary interaction.

One star is difficult to analyze and therefore is not included in the statistics of the dacay.

The nine remaining "particles" of the secondary stars were classified as decays of short-lived particles. Their main characteristics are given in Table I. We note that two secondary stars of the type $0+0+4n$ have among their decay products a single electron, and moreover, the event 10–70–213 has a single electron as part of the primary star (with the primary-star track closest to it belonging to a hadron). We emphasize that all the registered decays occurred at distances not exceeding 100 μm from the position of the primary star, whereas the remaining secondary stars were distributed approximately uniformly over the entire interval, 1000 μm. Estimates of the number of

TABLE I. Characteristics of decaying particles.

Type of decay	№	Number and type of primary star	l from primary star (μm)	Mass, GeV/c^2	γ	$\tau \times 10^{14}$ sec
$0 + 0 + 3p$	1	10 – 78 – 210 $(1 + 5 + 20p)$	63	2.2 ±0.3 $(\pi\pi\Sigma, K\pi p)$	33	0.65
	2	10 – 78 – 097 $(1 + 3 + 35p)$	90	2.1 ±0.3 $(K\pi p)$	23	1.3
$0 + 0 + 2n$	3	10 – 70 – 090 $(5 + 2 + 21p)$	25	2,1 ±0,3 $(\pi\Sigma)$	22	0,4
	4	10 – 74 – 236 $(5 + 3 + 18p)$	29	2,0 ±0,2 $(\pi\Sigma)$	2,2	4.4
	5	10 – 74 – 341 $(13 + 7 + 42p)$	35	2.3 ±0,2 (Kp)	8	1.5
	6	10 – 78 – 277 $(6 + 12 + 17p)$	22	2,5 ±0.4 $(\pi\Sigma)$	3.2	2.3
$0 + 0 + 4n$	7	10 – 70 – 002 $(15 + 3 + 20p)$	28	2.0 ±0,4 $(K3\pi)$ 2,1 ±0,3 $(\Sigma 3\pi)$	23	0,4
	8	10 – 70 – 148 $(7 + 7 + 26p)$	77	2,2 ±0,3 (for $e2\pi\Sigma$)	8,8	2,9
	9	10 – 70 – 213 $(1 + 1 + 7p)$	12	2,5 ±0.4 (for $e2\pi\Sigma$)	67	0,06

events that are produced in an interval up to 100 μm as a result of known processes and imitate the decays, are given in Table II. It follows from Table II that the number of background events is much lower than the observed number of decays.

4. An estimate of the mass of the decaying particles, made under various assumptions concerning the nature of the decay products, has shown that in all cases mass values close to 2 GeV/c^2 are possible (in six cases it is necessary for this purpose to assume the presence of a baryon among the decay products). This circumstance served as evidence that the observed events are decays of charmed particles, for the most part baryons. The decay modes that lead to an initial-particle mass in the region of 2 GeV/c^2 are given in Table I. In two cases we must assume the presence of a semileptonic decay. In this case only a lower bound can be obtained for the mass of the initial particles. The type of the initial particle in these cases is not rigorously determined.

TABLE II. Background for decays in 100 m interval.

Type of decay	Observed number of events	Estimated background	Background source
$0+0+3p$	2	$\lesssim 10^{-2}$	Secondary interaction (coherent generation)
$0+0+2n$	4	$\lesssim 4\times10^{-2}$	The decays $K_s^0\to2\pi$ and $\Lambda\to p\pi$ Secondary interaction of neutral particles
$0+0+4n$	3	$\lesssim 2\cdot10^{-3}$	Secondary interaction of neutral particles

On the basis of the data of Table I we plotted the dependence of $N(>\tau)$ on τ, where τ is the time elapsed prior to decay in the rest system of the decaying particle. All the data were summed. The resultant dependence (see Fig. 1) is close to a straight line in a semilog scale. This can mean that the lifetimes of the different charmed particles differ little from one another (at least for baryons). The characteristic lifetime that follows from Fig. 1 is $\tau_0 = 1.5\times10^{-14}$ sec.

No associative production was reliably fixed in all the discussed events. An exception is the star 10–70–213, in which electron emission from the point of the primary interaction was observed. Its appearance is most likely due to the decay of a second charmed particle (possibly a D meson). It must be assumed here that the lifetime of the D mesons is several times shorter than τ_0, and that their decays occur in the immediate vicinity of the center of the star ($\leqslant 10\,\mu$m) and are not reliably identified. The presented data yield to a yield ratio $Y_{em}^{ch}/Y_{em}^{inel}\approx10^{-2}$. Starting from the empirical relation[12] $\sigma_A^{\psi} = A\sigma_N^{\psi}$ and assuming that $\sigma_A^{ch} = A\sigma_N^{ch}$, and also using[13,14]

$$\sigma_A^{inel} = A^{3/4}\sigma_N^{inel} \quad [13,\ 14]$$

we have

$$Y_{em}^{ch}/Y_{em}^{inel} = \frac{\sigma_N^{ch}\sum\limits_{em} n_i A_i}{\sigma_N^{inel}\sum\limits_{em} n_i A_i^{3/4}} = 2.7\,\frac{\sigma_N^{ch}}{\sigma_N^{inel}}\ .$$

Therefore at $\sigma_N^{inel}\approx33\ \mu$b we get the estimate $\sigma_N^{ch}\approx120\ \mu$b, which agrees with the direct-neutrino data.[4–6]

The authors thank the FNAL management and the Division of Nuclear Physics of the USSR Academy of Sciences for collaboration in the irradiation of the nuclear emulsions with the FNAL accelerator, Prof. L. Voivodich and I.V. Chuvilo for help with the irradiation run, and E.A. Krupetskova and M.V. Tyurina for scanning and measurements.

1)Experiments performed by electronic methods yield an upper bound $\sigma_N^{ch} \lesssim 20\text{–}30\ \mu\mathrm{b}$. Taking into account the number of assumptions made in obtaining these estimates of σ_N^{ch}, the discrepancy between the deductions of the two groups of experiments may not be so large.

2)A number of preliminary results of the present investigation and the procedure are reported in the Diploma Thesis of N.A. Salmanova (Moscow State University, December, 1977).

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