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SEARCH FOR SHORT LIVED PARTICLES PRODUCED BY 300 AND 400 GEV/C PROTONS IN NUCLEAR EMULSIONS

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Abstract: In a search for charmed particles produced by 300 and 400 GeV/c protons in nuclear emulsions, no reliable candidate was found among 16.000 interactions. This implies an upper limit of 7 μb (90% confidence level) for the associated production of charmed particles with lifetimes between 3×10^{-15} and 3×10^{-13} sec.

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1. Introduction

At present, there is a considerable experimental effort on the search of charmed particles, which should have masses around 2 GeV, lifetimes of the order of 10^{-13} seconds and should be produced in pairs in hadron-hadron collisions[1]. The interest on charmed particles was awakened first by the discovery of weak neutral currents and of the J/ψ particles. Indications and/or evidence for the existence of charm particles came from several experiments[2-9].

The short lifetimes involved in the decays of charmed particles make their direct observation (direct in the sense of separating production and decay vertices) possible only in nuclear emulsions. A charm event candidate would have two particles (charged or neutral) decaying into two or more particles, the decay vertices being connected to the primary production vertex.

This paper describes a search for the associated production of charmed particles in the interactions of 300 and 400 GeV/c protons with emulsion nuclei. We have chosen rather high momenta in order to be well above any possible thresold and to have higher production cross sections.

2. Exposures and scanning

Two stacks of Ilford G5 emulsions have been exposed to protons of 300 and 400 GeV/c respectively at the Fermilab accelerator. The first stack, made of 80 plates, each 600 μm thick and 10×10 cm^2 in area, received about 10^5 protons per cm^2. The second stack, made of 80 plates each 500 μm thick and 5 x 10 cm^2 in area, received about 3 x 10^4 protons per cm^2. The development of the emulsions was performed at CERN.

Using standard microscopes, with 10 x wide field oc, 22 x ob, we performed an area scan for primary proton interactions in a band perpendicular to the beam direction, covering on each plate an area of 2 x 8 cm^2 at 300 GeV/c and 0.5 x 6 cm^2 at 400 GeV/c. The scanning area was chosed at the entrance of the beam in order to minimize the number of secondary interactions. We have scanned a total of 56 plates.

Once an interaction was found, it was carefully looked for decays of neutral and charged particles coming from the interaction point. The decays were looked for in an area which extended 300 μm around the primary vertex and 600 μm downstream of it. This was realized by scanning in one field of view (600 μm in diameter) centered on the primary vertex and in a second one displaced by half a field forward in the direction of the incoming protons. When an interaction with a large multiplicity is involved, it is difficult to observe decays at small distances from the production vertex. Thus we have a loss of events when the distance between primary and secondary vertex is smaller than 10 μm.

Candidates of charmed particles decays (single or double) had to have no black tracks coming from the secondary vertex. Moreover: (i) The decay of a neutral particle into two charged prongs was recorded if the opening angle was larger than three degrees. This cut removed the majority of converted photons. (ii) A charged particle decaying into one charged prong was recorded if it had a minimum deflecting angle of 3°.

The candidates were later reexamined by a physicist and a more thorough search for associated decays was made up to a distance of two millimiters downstream of the primary interaction.

Table 1 gives a summary of the number of interactions analyzed and of single and double decay candidates. The total number of interactions analyzed is 16098. Of these 3780 had no visible charged primary and presumably came from neutron (and photon) interactions (at 400 GeV/c we only analyzed a few of these interactions). The table gives also the number of single decay candidates, classified in neutral and charged particle decays; there is a further classification according to the number of charged prongs originating from the decays.

Some decays of hypernuclei within a distance of 30 μm from the primary vertex were also recorded for part of the scanning. We were interested in those hypernuclei with an unusually high release of energy in their decay as it could come from the decay of a bound charmed particle. None of such event was found.

3. Detection efficiency and background

The detection efficiency is affected by a large number of factors, the most important of which is represented by the decay lifetimes of the charmed particles. The efficiency was studied with a Montecarlo program, assuming associated production of charm particles according to pure phase space, with an average total multiplicity equal to $\langle n_s \rangle$ for the shower particles.

Fig. 1 shows the relative detection efficiency versus lifetimes for the observation of a single and double decay of particles with 2 GeV masses. The curves were computed at 300 GeV/c incoming momentum, assuming $\langle n_s \rangle = 12$, a minimum visible length of 10 μm, a maximum decay length of 600 μm, in the beam direction for the first decay, a maximum of 2000 μm for the second decay and a plate thickness of 600 μm. The curves do not take into account the scanning efficiency (estimated to be about 90%), the efficiency due to the cut-offs in the opening angle of a V°, in the decay angle of a charged particle, into a charged one, and the loss due to the decay of a neutral particle into neutral ones. All these effects are estimated to yield a combined efficiency of about 80% for the single decays and slightly less for the double decays.

The curves change slightly, when changing primary energy (from 300 to 400 GeV/c), charmed particle masses, cut of the decay lengths in emulsion and mean multiplicity factors. Thus we are able to measure with some efficiency lifetimes between 10^{-15} and 10^{-12} sec. (Fig. 1).

Background events which can simulate the production of one or of a pair of charmed particles come from secondary interactions on neutrons, conversion of photons in e^+e^- pairs, decays of strange particles, etc. Being able to identify electrons with good efficiency, we estimate that from known sources we have about 2×10^{-3} events per interaction which may simulate the production and decay of a single charmed particle. The background for double charm production and decay is much lower, around 10^{-5} events per interaction. For this reason, we concentrate the analysis on associated production and decay.

4. Result and discussion

The 37 single-decay candidates are compatible with the background estimate; moreover their path length distribution is essentially flat (Fig. 2).

We have no acceptable candidate with two observed decays. Taking into account the average detection efficiency and the number of observed interactions, we can give an upper limit of $\sigma \lesssim 7\ \mu b$, (90% confidence level) on the hadronic associated production and decay of short lived particles at Fermilab energies with a lifetimes in the range $3 \times 10^{-15} \div 3 \times 10^{-13}$ seconds and a mass smaller than 4.5 GeV.

The charm particle candidates found in nuclear emulsions are of the single decay type[8,9] (with the exception of a cosmic ray event) and of difficult interpretation. Negative results for double decay events have been obtained in a similar emulsion experiment, using slightly different scanning criteria [10].

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References

1) M.K. Gaillard, B.W. Lee, and J.L. Rosner, Rev. Mod. Phys. 47 (1975) 277.

2) A. Benvenuti et al., Phys. Rev. Lett. 34 (1975) 419; 35 (1975) 1249.

3) J. Blietschau et al., Phys. Lett. 60 B (1976) 207; J. von Krogh et al., Phys. Rev. Lett. 36 (1976) 910.

4) E. Cazzoli et al., Phys. Rev. Lett. 34 (1975) 1125.

5) J. Siegrist et al., Phys. Rev. Lett. 36 (1976) 700; G. Goldhaber et al., Phys. Rev. Lett. 37 (1976) 255; I. Peruzzi et al., Phys. Rev. Lett. 37 (1976) 569; B.H. Wiik, Rapporteur talk at the 1976 Int. Conf. on High Energy Physics at Tbilisi (1976).

6) B. Knapp et al., Phys. Rev. Lett. 37 (1976) 882.

7) E.H.S. Burhop et al., Phys. Lett. 65B (1976) 299.

8) For an analysis of emulsion results see for example: T.K. Gaisser, BNL 21124 (1976) and T.K. Gaisser and F. Halzen, Nucl. Phys. (submitted) Jan. 1976. K. Niu et al., Progr. Theor. Phys. 46 (1971) 1644; H. Sugimoto et al., Progr. Theor. Phys. 53 (1975) 1541; K. Hoshino et al., Progr. Theor. Phys. 53 (1975) 1859; A.A. Komar et al., JEPT Lett. 21 (1975) 239; P.L. Jain et al., Phys. Rev. Lett. 34 (1975) 1239.

9) Yu. A. Batusov et al., "Search for superfragments in proton-nuclear interactions at 70 and 250 GeV," Proceedings of the 1976 Int. Conf. on High Energy Physics, Tbilisi (1976).

10) G. Coremans-Bertrand et al., "A search for charmed particles originating from the interactions of 300 GeV/c protons in emulsion nuclei", Phys. Lett., to be published.

Table 1. Number of interactions from primary protons and neutral particles analyzed at 300 and 400 GeV/c. The number of single decay candidates have been found at a distance from 10 to 600 μm from the primary interaction vertex.

Energy (GeV)	Interactions due to protons	Interactions due to neutrals	Single decays neutral 2 prongs*	Single decays neutral 4 or more	Single decays charged 1 prong+	Single decays charged 3 or more	Double decays
300	5092	3009	5	3	6	2	0
400	7226	771**	1	4	11	5	0
Total	12318	3780					
	16098						

* With an opening angle larger than 3°.

+ With a deflecting angle, larger than 3°.

** These correspond to only part of the scanning.

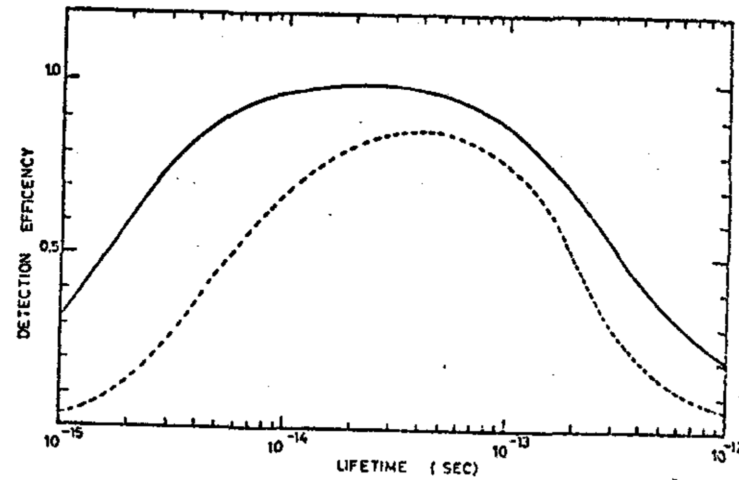

Fig. 1 Relative detection efficiency versus lifetimes for the observation at 300 GeV/c of the decay of [illegible] GeV particles, assumed to be produced in pairs; a) for the observation of a single decay particle (solid line); b) for the observation of both decay particles (dashed line). At 400 GeV/c the two curves move slightly toward smaller lifetimes.

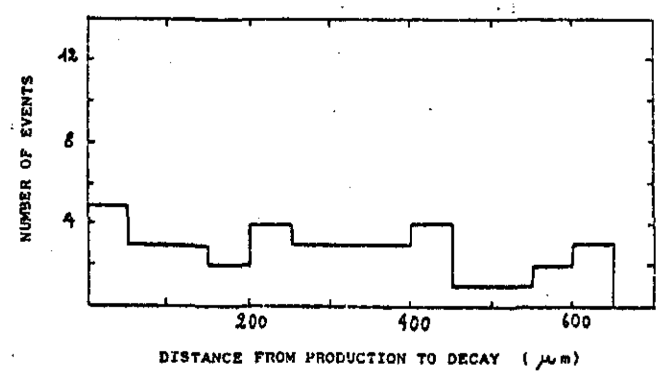

Fig. 2 Path length distribution of single decay candidates.