A SEARCH FOR CHARMED PARTICLE PRODUCTION IN π-d INTERACTIONS AT 200 GeV/c*

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A search for hadronic production of charmed particle pairs decaying into a V^0 and a μ was performed using the FNAL 30-inch deuterium bubble chamber and a downstream μ detector. In the mass region 2–2.5 GeV, upper limits of 90 μb, 340 μb, and 350 μb are set on $\Gamma\sigma$ for the K^0 mode assuming three different production and decay models. Upper limits for higher charm masses and Λ modes are also given.

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A recent search [1] for hadronic production of charmed particles [2] has been reported for π^+p interactions at 15 GeV/c giving upper limits for the production cross section times the branching ratio into *purely hadronic* final states (including a strange particle) for a variety of production and decay channels. The experiment was sensitive to charmed particles in the 1.5 to 4.0 GeV mass region, resulting in upper limits of a few tens of microbarns for each exclusive channel. Subsequent experiments [3, 4] have extended these limits for a variety of hadronic decay modes to the range of tens of nanobarns for n-Be interactions ($2 \leqslant M_c \leqslant 3$ GeV) and tenths of nb for e^+e^- interactions ($1.5 \leqslant M_c \leqslant 2.4$ GeV).

On the other hand, several new effects [5–7] have been reported which may be interpreted as arising from charmed-particle production. This interpretation would in two cases [5, 6] require the charmed particles to decay leptonically or semileptonically. None of these effects is directly contradicted by the above-quoted charm searches.

Although the branching ratio for charmed particle decays into purely hadronic modes is expected to be large, in analogy with the nonleptonic decays of hyperons, this is by no means a necessary assumption [8]. Hence from the standpoint of placing upper limits on charmed-particle production cross sections one must also consider the case of leptonic or semileptonic decays. Here the experimental situation is much less clear. Upper limits may be derived from the measurements [9–11] of direct muon production at high transverse momentum [12]. In Ref. [11] an upper limit of 2 μb is given for a 3.1 GeV charmed particle with a three-body semileptonic decay mode assuming a particular production model which peaks at $p_L^* = 0$. It is not clear from the published data what limit may be deduced for other production models.

Because the direct muon production experiments accept only muons with $p_T \geqslant 1$ GeV/c [1] their interpretation as a limit on charmed-particle production is not simple. For the interesting mass region $2 \leqslant M_c \leqslant 3$ GeV no such interpretation has yet been published, but one expects that the experiments are relatively insensitive to such particles. This may be seen from the following considerations: For a charmed particle produced with $p_T = 0$ and decaying into $K^0\mu\nu$ the *maximum* transverse momentum of the μ is 1 GeV/c for $M_c = 2.5$ GeV; hence the experimental acceptance must cut off near this mass. For a $\Lambda^0\mu\nu$ decay mode the corresponding cutoff is $M_c = 3$ GeV. We therefore conclude that charmed particles may be produced in this mass region with quite large cross sections without contradicting these experiments.

In this paper we report a search for charmed particles with semileptonic decays. The experiment accepts muons with $\theta_{LAB} \leqslant 85$ mr and is most sensitive to charmed particles in the $2 \leqslant M_c \leqslant 3$ GeV mass region. If one accepts the charmed-particle interpretation of Ref. [5] one might expect a very large signal in this region.

The data are a part of a 70 K picture exposure of the FNAL 30″ deuterium filled bubble chamber to a 200 GeV/c tagged π^- beam. A sample of 13 K pictures are obtained

[1] In fact, only Ref. [11] goes to $p_T = 1$ GeV/c. For the quoted experiments the acceptances are as follows: Ref. [9]: lab angle 77 mr, $p_T \geqslant 1.5$ GeV/c, CMS angle 90°; Ref. [10]: lab angle 83 mr, $p_T \geqslant 2$ GeV/c, CMS angle 90°; Ref. [11]: lab angle 80 mr, $p_T \geqslant 1$ GeV/c, CMS angle depends incident energy.

with a downstream muon detector. The signature for charmed particle production was taken to be the combination of (1) a particle which penetrated the muon shield (laboratory angle $\lesssim$ 85 mr and $\gtrsim$ 9 GeV/c) and (2) a V^0 observed in the bubble chamber. No evidence for charmed-particle production has been found within the limits of our sensitivity.

The apparatus is shown in Fig. 1. The muon detector consists of a 3′ lead and a 14′ concrete shield followed by a plane of six 18″ square counters. The logical sum of the outputs of these counters was put into coincidence with the beam particle tag and the

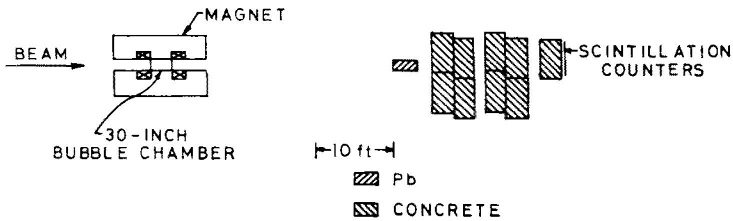

Fig. 1. The experimental apparatus

output of this coincidence was used to identify the beam track. This resulted in a sample of 1600 beam tracks for which a particle penetrated the downstream muon detector. This sample consists of (1) muons which contaminate the beam, (2) ordinary hadron events for which a secondary hadron either decayed into a muon or punched through the shielding, and (3) directly produced muons, or muons from decay of charmed particles if they exist.

Of the 1600 μ-tagged beam tracks 72 were found to be associated with an interaction. These 72 events are considered to be candidates for the production of charmed particles. Of these, only 3 events had an associated V^0. From the measured rate of V^0 production per primary interaction in events without a muon tag, we expect 3.2 V^0's in a sample of 72 primary events. We therefore conclude that the V^0 production rate in the sample of candidates for charm production is consistent with that in a sample of ordinary hadron events where the μ tag could come from secondary decays or punch through of hadrons. Thus we see no evidence for production of charmed particles nor any new objects which decay semileptonically into strange particles. The upper limit inferred (90% confidence level) is 6.0×10^{-4} of the $\pi^- d$ interactions rate, or 23 μb for the production of states which yield (1) a detected muon and (2) a detected V^0 in the bubble chamber. This is an upper limit on the *product* of the production cross section, the branching ratio into a muon and a short-lived neutral particle, and the detection efficiency of our apparatus.

The detection efficiency was calculated by generating events using Monte Carlo techniques and determining the probability that both the V^0 and the μ are detected. Charmed mesons are assumed to decay into $K^0\mu\nu$ with a matrix element like that of Ke_3 decay[2]. Charmed baryons are assumed to decay into $\Lambda\mu\nu$ with a constant matrix element. For the production mechanism, we assume associated production and consider separately the cases (*i*) where the detected V^0 and μ came from the same charmed particle and (*ii*) when they came from different charmed particles.

[2] A constant matrix was also considered. It gave the same result for the detection efficiency as did the Ke_3 matrix element.

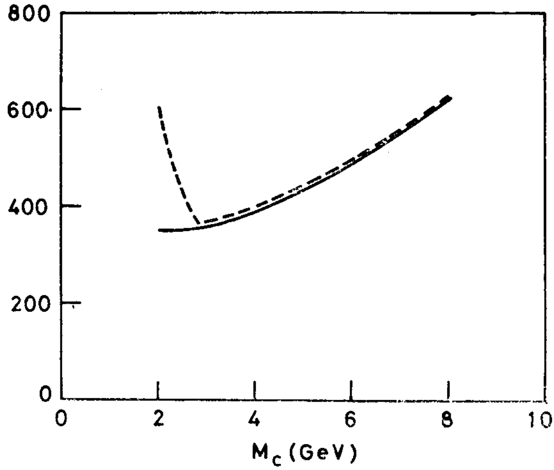

Fig. 2. Upper limits on the production cross section times branching ratio vs. assumed charm mass for $\pi^- d \to C\bar{C}X$, where either C or $\bar{C}$ is produced with $-2.5 \leqslant p_L \leqslant 6.5$ GeV/c and decays into $V^0 \mu\nu$. Solid curve: assuming that the V^0 is a K^0; dashed curve: assuming that the V^0 is a Λ

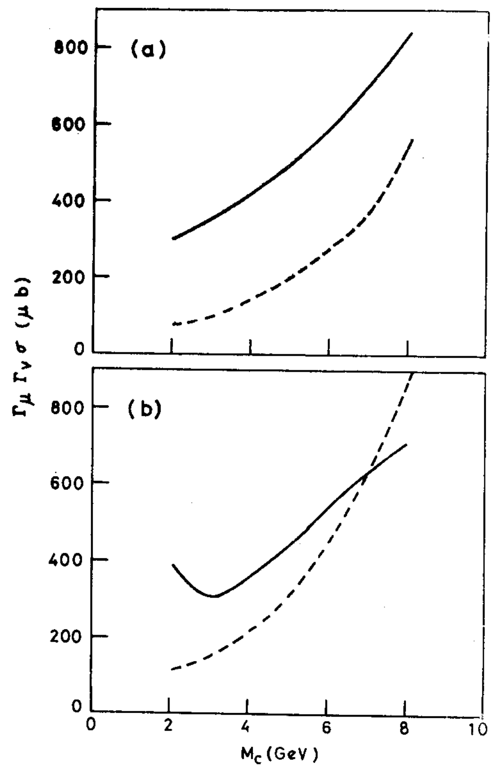

Fig. 3. Upper limits on the production cross section times branched ratios for $\pi^- d \to C\bar{C}X$ where one of the charmed particles is assumed to decay into a μ and the other into a V^0. (a) The V^0 is taken to be a K^0. Solid curve is for central production as defined in the text. Dashed curve is for forward-backward production of a pair of charmed mesons. (b) The V^0 is taken to be a Λ. Solid curve is for central production. Dashed curve is for forward-backward production to the charmed meson-baryon pair

In the case where the μ and V^0 come from the same semileptonic charmed particle decay, we assume a constant cross section in the c. m. longitudinal momentum region $-2.5 \leq p_L^* \leq 6.5$ GeV/c and we assume that the transverse momentum has a gaussian distribution with a mean of .35 GeV/c (the p_T dependence has a negligible effect on the results for $p_T \ll$ mass of the charmed particle). The corresponding upper limits on the cross section times branching ratio as a function of charmed particle mass are shown in Fig. 2.

In the case where the detected μ is produced by one charmed particle and the V^0 by the other, the calculation of detection efficiency is less sensitive to the choice of decay mode. However, the additional question of production correlations between the two charmed particles becomes important. We consider two regions: (a) "central production", where both charmed particles are produced uniformly in $-3 \leq p_L^* \leq 3$ GeV/c, and either may decay to a V^0, and (b) "forward-backward production", where one charmed particle is produced with $p_L^* \geq 0$ and decays to a μ and the other charmed particle is produced with $p_L^* \leq 0$ and decays to a V^0. The result, shown in Fig. 3, is an upper limit on the product $\sigma\Gamma_\mu\Gamma_V$, where σ is the production cross section, Γ_μ is the branching ratio into semileptonic muonic modes and Γ_V is the branching ratio into $K^0\Lambda$ modes. We note that if the production were strongly peaked forward-backward, the upper limit (b) would be smaller.

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[12] The only low transverse momentum data of which we are aware (L. B. Leipuner et al., *Phys. Rev. Lett.* **34**, 103 (1975)) is at or below 28 GeV/c incident momentum, which may well be below the energy at which charm production becomes appreciable. We note that production of $\psi(3700)$ is not observed at these energies.