Search for D^{*-} Production with a 16-GeV/c π^- Beam

S. U. Chung, A. Etkin, R. C. Fernow, K. J. Foley, J. H. Goldman,[(a)] H. Kirk, W. A. Love, T. W. Morris, S. Ozaki, E. D. Platner, S. D. Protopopescu, A. Saulys, D. P. Weygand, C. D. Wheeler, and E. H. Willen
Brookhaven National Laboratory, Upton, New York 11973

and

J. Bensinger and W. Morris
Brandeis University, Waltham, Massachusetts 02154

and

S. J. Lindenbaum
Brookhaven National Laboratory, Upton, New York 11973, and City College of New York, New York, New York 10031

and

M. A. Kramer and U. Mallik[(b)]
City College of New York, New York, New York 10031

and

Z. Bar-Yam, J. Dowd, W. Kern, and M. Winik[(c)]
Southeastern Massachusetts University, North Dartmouth, Massachusetts 02747

and

J. Button-Shafer, S. Dhar,[(d)] and R. Lichti[(e)]
University of Massachusetts, Amherst, Massachusetts 02154

(Received 2 December 1981)

A search for production of D^{*-}'s using the decay chain $D^0\pi^-$, $D^0\to K^+\pi^-$, was carried out at the Brookhaven National Laboratory multiparticle spectrometer with a 16-GeV/c π^- beam and a hydrogen target. At 95% confidence level the upper limits for the product of peripheral production cross section by branching ratio are 2.4 nb for inclusive D^{*-} production and 1.3 nb for the exclusive channel $\pi^- p\to D^{*-}\Lambda_c$.

PACS numbers: 14.40.Jz, 13.85.Ni

The detection of charm in hadronic processes has proven to be very difficult, mainly because the cross sections are $\sim 10^{-3}$ or less of the total cross section.[1] This fact combined with small branching ratios requires experiments with high sensitivity and good background rejection. One way to achieve the latter is to make use of the decay chain $D^{*-}\to D^0\pi^-$ and $D^0\to K^+\pi^-$ which has been observed in e^+e^- collisions by Feldman *et al.*[2] and also in ν and photoproduction experiments.[3] The very small Q value ($m_{D^*}-m_D-m_\pi=5.7\pm0.4$ MeV) for the D^* decay makes it possible to reduce the background significantly. This technique was used by Cester *et al.*[4] to search for D^{*-} production near threshold with a π^- beam at 10.5 GeV/c and obtained an upper limit on the product of cross section by branching ratio (σB) of 40 nb at 95% confidence limit (CL). It was also used by Fitch *et al.*[5] with a π^- beam at 200 GeV/c. Their data show a 2.7 standard deviation signal corresponding to a σB of ~ 70 nb. We report here the results of a search for peripheral D^{*-} production in the reaction

$$\pi^- p\to D^{*-}+X \tag{1}$$

and in particular in the exclusive channel

$$\pi^- p\to D^{*-}+\Lambda_c^+ \tag{2}$$

with a π^- beam at 16 GeV/c. We have obtained upper limits (95% CL) for σB of 2.4 nb for reaction (1) and 1.3 nb for reaction (2), an improvement of more than a factor of 20 over the previous measurement at a comparable energy.[4] In comparison to the measurements of Fitch *et al.*[5] this indicates that the cross sections for peripheral D^{*-} production are more than 20 times lower at energies accessible at the alternating gradient synchrotron.

This experiment was performed at the Brookhaven National Laboratory multiparticle spectrometer (MPS) with a 16-GeV/c π^- beam and a 60-cm-long liquid-hydrogen target. The apparatus has been described in a previous publication.[6] The trigger required a fast forward K^+ with momentum between 6.5 and 11.0 GeV/c identified by two large Cherenkov counters downstream of the MPS with γ thresholds of 20 and 13. To select a K^+ in the right momentum range the trigger utilized two sets of three-dimensional coincidence logic systems implemented via random-access memories.[7] The elements used in the logic were two multiwire proportional chambers inside the MPS magnet and a large scintillator hodoscope behind each of the two downstream Cherenkov counters. In addition, there was also a minimum angle requirement between the K^+ and the incident beam to decrease the trigger acceptance of low-mass $K^+\pi^-$ pairs and a multiplicity requirement to select events with three or more tracks. Particles associated with each event were detected with spark chambers on both sides as well as downstream of the target.

A total of 2.5×10^6 K^+ triggers were recorded and analyzed, corresponding to a raw sensitivity of 68 events/nb. The events were processed in two stages. The first stage consisted of pattern recognition and a fast momentum and vertex-fitting program. The second stage involved a track-fitting program designed to perform iterative fits to spark-chamber measurements and beam parameters simultaneously. The parameters in the latter fit were the vertex position and the vector momentum of each track. This fit improves the resolution on effective and missing masses by 30%. The resolution was calculated with the full error matrix obtained from the fit. The error calculations were checked using four-constraint events from the reaction $\pi^-p \to \pi^-p\bar{p}p$ (see Ref. 6). The errors calculated from the covariance matrix for the missing momenta and energy and all other derived quantities matched the observed distributions within 10%. Our effective-mass resolutions and systematics were also checked by studying $\Lambda \to p\pi^-$ and $K_s \to \pi^+\pi^-$ events and we believe them to be well understood.

Before the processing of the K^+ trigger events through the second stage, events were selected which, in addition to a K^+ track between 6.5 and 11.0 GeV/c, had at least two reconstructed negative tracks. A further requirement was that a $K^+\pi^-$ effective mass be between 1.77 and 1.96 GeV, Q less than 25 MeV, and a missing mass (MM) recoiling off $K^+\pi^-\pi^-$ greater than 2.0 GeV. A total of 350 events were found satisfying these criteria. We show in Fig. 1 the effective-mass, the Q, and the missing-mass distributions for these events after the second stage of processing. For comparison, we also show the $K^+\pi^-$ effective-mass spectrum requiring only one or more negative tracks at the production vertex in addition to the triggered K^+. One can see from Fig. 1(a) that the cuts (primarily that of $Q<25$ MeV) reduce the background by at least a factor of ~100. The cal-

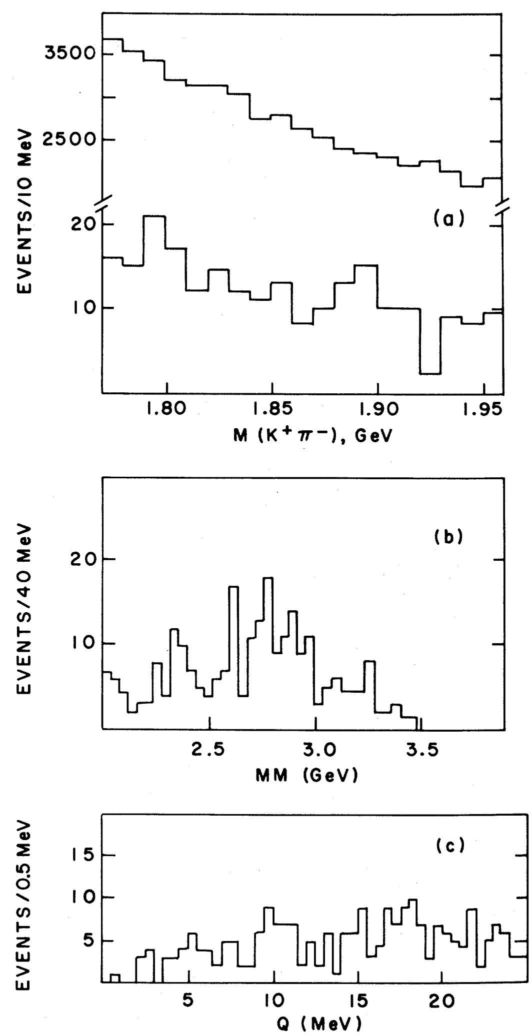

FIG. 1. (a) $K^+\pi^-$ effective-mass spectrum. Top histogram shows all events between 1.77 and 1.96 GeV, bottom histogram shows remaining events after requiring at least one additional negative track, MM >2.0 GeV, and $Q<25$ MeV. (b) Missing-mass spectrum off $K^+\pi^-\pi^-$ (MM) for $K^+\pi^-$ mass between 1.77 and 1.96 GeV and $Q<25$ MeV. (c) Q spectrum for events with $K^+\pi^-$ mass between 1.77 and 1.96 GeV and MM>2.0 GeV.

culated $K^+\pi^-$ effective-mass resolution (rms) in the selected mass range is typically better than 10 MeV.[8] The MM resolution is calculated to be 45 MeV.

To estimate the acceptance, Monte Carlo events were generated with the D^{*-} produced peripherally with an $e^{2.7t}$ distribution. The acceptance is actually fairly insensitive to the slope of the t distribution.[9] These Monte Carlo events were processed through the whole chain of the data-reduction programs. The overall acceptance is 6.4% at the Λ_c^+ mass (2.26 GeV) and varies slowly as a function of MM between 2.2 and 3.0 GeV; above 3.0 GeV it decreases rapidly. There are additional losses due to inefficiencies of the trigger elements, beam losses, etc., which reduce the acceptance by an additional 30%. The visible sensitivity for observing $D^{*-}\to D^0\pi^-$ ($D^0\to K^+\pi^-$) is 3.0 events/nb for MM < 3.0 GeV.

To reduce the background significantly we made use of the very small Q value for the decay $D^{*-}\to D^0\pi^-$, i.e., $Q=m_{D^*}-m_{D^0}-m_\pi=5.7\pm0.4$ MeV.[1] The experimental error on Q turns out to be small if Q is small, because the partial derivatives of Q with respect to the momenta are very small, typically $\lesssim 10^{-2}$. The error on momentum measurements in the MPS is less than 1% for most tracks; so each track contributes only a fraction of 1 MeV to the error on Q. The calculated error on Q (with use of the full covariance matrix) is $\lesssim 0.7$ MeV (rms).

In Fig. 2 we show a scatter plot of Q vs MM for events with $K\pi$ effective mass between 1.82 and 1.90 GeV. For MM < 3.0 GeV there are 10 events in the range $3.7 < Q < 7.7$ MeV. From studying events outside this Q range and also those outside the selected $K\pi$ mass range, we estimate the background to be 11 events. Thus we obtain an upper limit on σB for D^{*-} production of 2.4 nb at 95% CL. Using the branching ratios 0.64 ± 0.11 (Ref. 2) for $D^{*-}\to D^0\pi^-$ and 0.03 ± 0.006 (Ref. 10) for $D^0\to K^+\pi^-$ we obtain a cross-section upper limit of 130 ± 30 nb, where the error reflects the uncertainties in the branching ratios.

In the MM range from 2.14 to 2.38 GeV and the Q range from 3.7 to 7.7 MeV, there is only one event and the estimated background is one event. This gives an upper limit on σB of 1.3 nb for the exclusive reaction $\pi^-p\to D^{*-}\Lambda_c^+$ and a corresponding cross-section upper limit of 70 ± 18 nb.[11] In Fig. 3 we show the cross-section upper limits as a function of MM for D^{*-} production.

In conclusion, we have searched for peripheral D^{*-} production with a π^- beam at 16 GeV/c and, by making use of the very small Q value for $D^{*-}\to D^0\pi^-$ decay with good resolution, we were able to reduce the background to a negligible level. Our 95% confidence level upper limit on σB is 2.4 nb for inclusive D^{*-} production and 1.3 nb for the exclusive channel $\pi^-p\to D^{*-}\Lambda_c^+$. With use of branching ratios from Refs. 2 and 10 the corresponding cross-section upper limits are 130 ± 30 and 70 ± 18 nb, where the errors reflect the uncertainties in the branching ratios. Our upper limits indicate that at 16 GeV/c peripheral D^{*-} production is more than a factor of 20 lower than at 200 GeV.

This research was supported in part by the

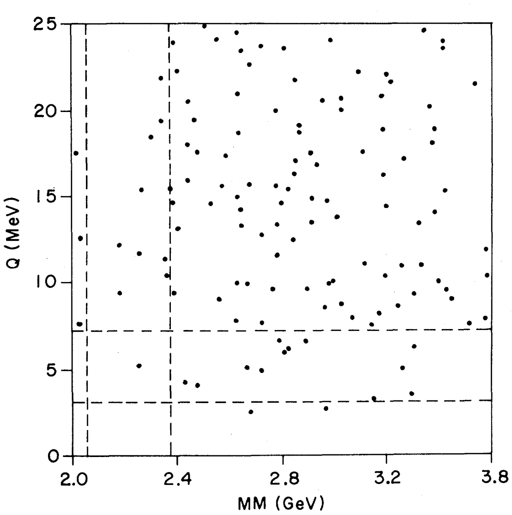

FIG. 2. Scatter plot of MM vs Q. The dotted lines indicate the ranges 2.14 < MM < 2.38 GeV and 3.7 < Q < 7.7 MeV.

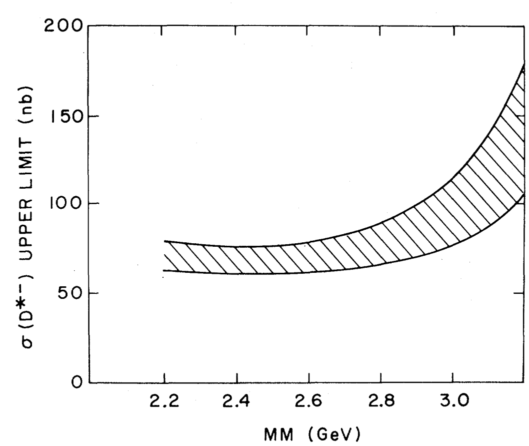

FIG. 3. Cross-section upper limits at 95% confidence level as a function of MM. The band indicates the uncertainties in the branching ratios.

U. S. Department of Energy under Contracts No. DE-AC02-76CH00016, No. EY-76-02-3230, No. DE-AC02-ER0-3330, by the National Science Foundation under Contract No. PHY-7924579, by the National Science Foundation, by the City University of New York Professional Staff Congress–Board of Higher Education Research Award Program, and by the Physics Department, Technion-Israel Institute of Technology.

---

[a]Present address: Florida State University, Tallahassee, Fla. 32306.

[b]Present address: Laboratoire de l'Accélérateur Linéaire, Orsay, France.

[c]Now at Brookhaven National Laboratory, Upton, N. Y. 11973.

[d]Present address: Mitre Corporation, Bedford, Mass. 01730.

[e]Present address: Texas Tech University, Lubbock, Tex. 79409.

[1]J. J. Aubert *et al.*, Phys. Rev. Lett. 35, 416 (1975) (limits given in this paper should be increased to $\gtrsim 10^{-32}$ cm^2 if peripheral production is assumed); R. C. Cester *et al.*, Phys. Rev. Lett. 37, 1178 (1976); S. Wojcicki, in *High Energy Physics—1980*, edited by L. Durand and L. G. Pondrom, AIP Conference Proceedings No. 68 (American Institute of Physics, New York, 1981), p. 1430.

[2]G. J. Feldman *et al.*, Phys. Rev. Lett. 38, 1313 (1977).

[3]J. Kirkby, in *Proceedings of the Ninth International Symposium on Lepton and Photon Interaction at High Energies, Batavia, Illinois, 1979*, edited by T. B. W. Kirk and H. D. I. Abarbanel (Fermilab, Batavia, Illinois, 1980), p. 107; J. Blietschau *et al.*, Phys. Lett. 86B, 108 (1979); P. Avery *et al.*, Phys. Rev. Lett. 44, 1309 (1980); J. E. Wiss, in *Experimental Meson Spectroscopy—1980*, edited by S. U. Chung and S. J. Lindenbaum, AIP Conference Proceedings No. 67 (American Institute of Physics, New York, 1981), p. 257.

[4]R. Cester *et al.*, Phys. Rev. Lett. 40, 138 (1978).

[5]V. L. Fitch *et al.*, Phys. Rev. Lett. 46, 761 (1981).

[6]S. U. Chung *et al.*, Phys. Rev. Lett. 45, 1611 (1980).

[7]E. D. Platner *et al.*, IEEE Trans. Nucl. Sci. 24, 1225 (1977).

[8]About 75% of the events have $\leq$ 10-MeV resolution; these events have the π^- from D^0 decays bending into the magnet. The other 25%, for which the π^- bends out of the magnet and thus goes through few chambers, have resolutions of the order of 30 MeV. Our cuts are wide enough to include most of these events.

[9]The slope used for the t distribution corresponds to that expected from D^0 exchange (under the assumption that the Regge trajectory has a slope of 0.4 GeV^{-2} as would be the case if $m_{D^{**}} - m_{D^*} = m_{K^{**}} - m_{K^*}$). If the slope is a factor of 2 lower, the acceptance only decreases by 10%.

[10]R. M. Schindler *et al.*, Phys. Rev. D 24, 78 (1981).

[11]Our upper limits are based on Poisson statistics. If the expected number of events to be observed is $\bar{n} = 4.8$, then the probability for observing 1 or 0 events is 5%. This gives then an upper-limit signal of 3.8 events. Similarly if $\bar{n} = 17.0$, then there is a 5% probability of observing 10 or less events, giving an upper-limit signal of 7.0 events.