Measurement of D^* Production in Pion-Nucleon Interactions at 200 GeV/c

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Results are reported of an experiment to measure the cross section for production of the D^{*+} (D^{*-}) in 200-GeV/c $\pi^- N$ interactions. We observe 78 ± 26 events corresponding to a D^*-production cross section $d\sigma/dy = 1.6 \pm 0.5$ μb at $y = 0$.

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We report here the results of a search for production of the D^{*+} (D^{*-}) in the reaction $\pi^- + N \to D^{*+} + X$, $D^{*+} \to \pi^+ + D^0$, $D^0 \to K^- + \pi^+$ (and charge conjugate) at a beam momentum of 200 GeV/c. A number of experiments have indirectly measured the cross section for producing charm in hadronic interactions.[1] The only published result with a peak in a mass spectrum reports a very large forward cross section for D^+ production at the CERN intersecting storage rings (ISR).[2] To suppress the noncharmed background, the present experiment required observation of the pion from the D^* decay in coincidence with a $K\pi$ system at the D^0 mass. Since the Stanford Linear Accelerator Center (SLAC) branching ratio for $D^{*+} \to \pi^+ D^0$ is 60%, much of the D^0 signal comes from this decay. Because of the low Q value of the D^* decay (5.7 ± 0.5 MeV/c^2),[3] the pion is almost at rest in the D^0 center of mass, and only pions in a small region of phase space contribute to the background. This technique was used in a similar experiment at charm threshold,[4] and in a high-energy photoproduction experiment,[5] as well as in an e^+-e^- colliding-beam experiment in which the Q value was first measured.[3]

The experiment was performed at the Fermi National Accelerator Laboratory, using the high-intensity pion beam in the Proton-West area, with the apparatus shown in Fig. 1. (A detailed description of the apparatus is given in Ref. 6.) The 200-GeV/c π^- beam interacted in a 2.3-g/cm^2 beryllium target. The D^0 decay products were detected in a double-arm spectrometer, each arm of which contained a BM109 analyzing magnet with a transverse momentum of 650 MeV/c. These arms were equipped with scintillation-counter hodoscopes and drift chambers for charged-particle tracking. Two Cherenkov counters, with kaon thresholds at 10 and 17 GeV/c, provided pion-kaon separation from 5 to 18 GeV/c and kaon-proton separation above 11 GeV/c. The associated pion from the D^* decay was directed along the beam line with momentum between 1.0 and 2.5 GeV/c. A large-aperture magnet near the target bent this pion into two low-momentum arms also equipped with scintillation counters and drift chambers. These arms, which are shown in Fig. 2, accepted almost all pions associated with D^0's detected by the double-arm spectrometer. The momentum resolution $\delta P/P$ was about 1% in all arms. The $K\pi$ mass was measured to an accuracy of ± 14 MeV/c^2 at the D^0 and the resolution in Q value was ± 0.7 MeV/c^2.

The trigger required an opposite sign pair in the double-arm spectrometer, each with momentum greater than 5 GeV/c, accompanied by a pion with momentum 1.0–2.5 GeV/c and angle less than 50 mrad. The trigger also required that one and only one arm have a signal in the threshold Cherenkov counter located in the magnet, which had a pion threshold of 5 GeV/c. The sign of the track which fired the pion counter was required to be the same as that of the particle in the low-momentum arm, as required for a $K^+\pi^-\pi^-$ ($K^-\pi^+\pi^+$)

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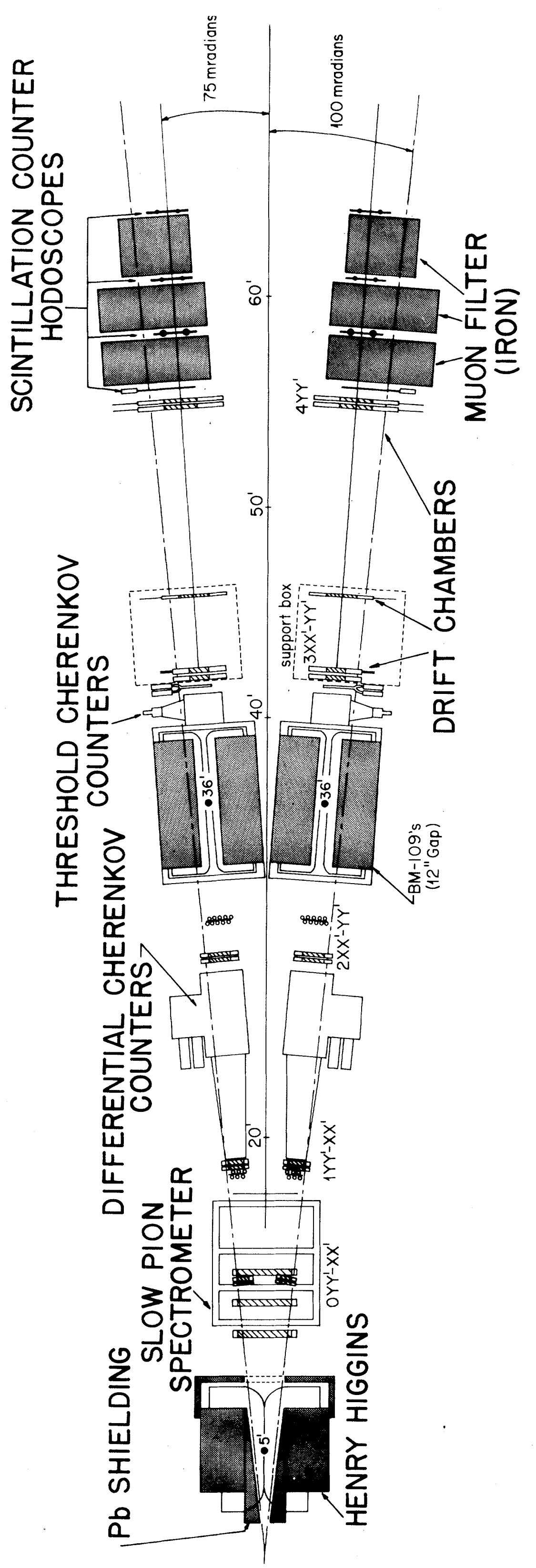

FIG. 1. Plan view of the apparatus.

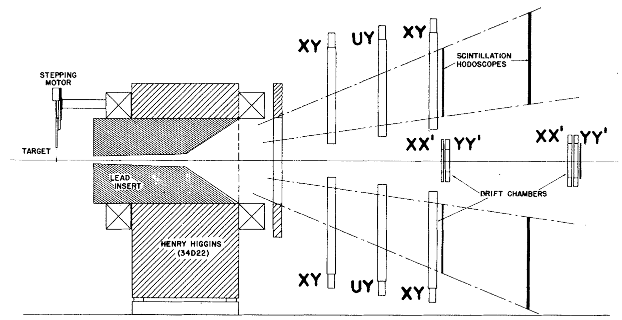

FIG. 2. Elevation view of the area near the target.

state. At a beam intensity of 7×10^7 pions per spill on target, we recorded fifty triggers per spill.

To be assured that the apparatus and analysis programs were functioning properly, we recorded two calibration reactions simultaneously with the D^* candidates. A convenient mass calibration for the double-arm spectrometer was provided by $\psi\to\mu^+\mu^-$ events. The ψ signal observed has a mass resolution consistent with that calculated from the experimental resolution and the number of events in the peak, together with the well-measured ψ cross section, provides an independent sensitivity check. We also observe a large number of Λ^0 decays, with the proton in one arm of the double-arm spectrometer and the pion in one of the low-momentum arms. The momentum regions covered by the Λ^0 decay products match those populated D^* decays, and thus the Λ^0 mass peak checks the operation of the low-momentum arms, as well as the ability to merge the two types of arms.

Figure 3 shows the Q-value spectrum for events with $1.835 < M_{K\pi} < 1.875$ GeV/c^2. A fit to the data with use of a Gaussian with $\sigma = 0.7$ MeV/c^2 above a smooth background gave a peak of 60 ± 22 events at a Q of 5.9 ± 0.3 MeV/c^2, to compare with the measured value of 5.7 ± 0.5 MeV/c^2. Correcting for the number of events outside the mass cut we calculate a total of 71 ± 26 D^* events. The background form used here was chosen by fitting to Q-value spectra for events in which the $K\pi$ mass was outside the D^0 region, with statistics an order of magnitude greater than the spectrum with a selection in the $K\pi$ mass.

Figure 4 shows the $K\pi$ invariant-mass distribution for events within the Q-value peak. δQ, the error on the Q value, had rather large variations depending on the kinematics of a particular event. We therefore defined a variable $R = (Q - Q_0)/\delta Q$,

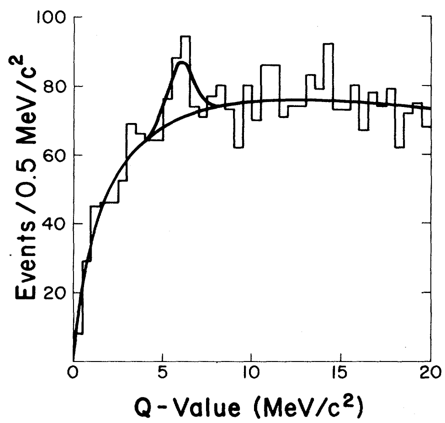

FIG. 3. The Q-value spectrum for events with $1.835 < M_{K\pi} < 1.875$ GeV/c^2. Both $K^+\pi^-\pi^-$ and $K^-\pi^+\pi^+$ events are included.

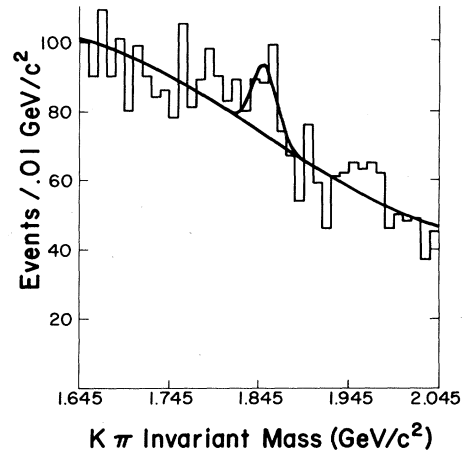

FIG. 4. The $K^\pm\pi^\mp$ invariant-mass spectrum for events within the cut on Q value defined in the text.

where $Q_0 = 5.8$ MeV/c^2 and δQ was calculated for each event, and applied a cut on R rather than Q. The events in Fig. 4 are those with $|R| < 1.4$, or those in which the calculated Q value is less than 1.4σ from the expected value. The background form was taken from fits to the $M_{K\pi}$ spectrum with no cuts on R, in analogy to the Q-value background described earlier. A fit to this background plus a Gaussian with $\sigma = 14$ MeV/c^2 found a peak of 72 ± 22 events at a mass of 1.852 ± 0.006 GeV/c^2. We estimate the systematic shift in the mass scale to be ± 7 MeV/c^2, so that the total error on the D^0 mass is ± 9 MeV/c^2. The mass value is in agreement with the measured D^0 mass of 1.863 ± 0.001 GeV/c^2.[7] Correcting for events outside the cut on R gives a total of 86 ± 27 events, in good agreement with the number deduced from the Q-value peak. The ability to fit the peak in both variables provides a check of our understanding of the background level under the D^*. No other peak of comparable significance occurs for any combination of $M_{K\pi}$ and Q. The fraction of D^* events with positive charge is 0.4 ± 0.2.

A Monte Carlo calculation with use of a production cross section of the form $E\,d^3\sigma/dp^3 = A(1 - |x|)^3 \exp(-1.1 p_T^2)$ gives a geometric acceptance of 3.5×10^{-4}. Using the total integrated flux of 1×10^{13} pions on target with calculated trigger and analysis efficiencies, we calculate the sensitivity to be 0.59 events/nb of cross section times branching ratio. The branching ratios for $D^{*+} \to \pi^+ D^0$ and $D^0 \to K^-\pi^+$ are 0.64 ± 0.11 and 0.026 ± 0.004, respectively.[7] The sensitivity for D^* production, which depends on the production model used, is thus 9.3 events/μb. The sensitivity in $d\sigma/dy$, which is independent of model, is 25 events/μb. Using 78 ± 26 events for the D^* signal, an average of the two results quoted previously, and assuming equal contribution from D^{*+} and D^{*-}, we calculate the total production cross section to be

$$\sigma(D^*) = \tfrac{1}{2}[\sigma(D^{*+}) + \sigma(D^{*-})] = 4.2 \pm 1.4\ \mu\text{b}.$$

The corresponding differential cross section, which is insensitive to the y dependence assumed, is $d\sigma/dy = 1.6 \pm 0.5\ (\pm 0.7)\ \mu$b, where the first error is statistical only and the second includes a 30% uncertainty in the normalization. This result is consistent with the level of charm production expected from prompt-lepton experiments.[8]

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Lett. 81B, 250 (1979). The cross section measured, under the assumption that 15% of the $D^+ \to K^- \pi^+\pi^+$ decay goes through $K^{*-}(890)$, is $d\sigma/dy = 200$ μb.

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[6]S. S. Sherman, Ph.D. thesis, Princeton University, 1980 (unpublished).

[7]J. Kirkby, in *Proceedings of the Ninth International Symposium on Lepton and Photon Interactions at High Energies, Batavia, Illinois, 1979,* edited by T. B. W. Kirk and H. D. I. Abarbanel (Fermilab, Batavia, Ill., 1979).

[8]An analysis of the experiments listed in Ref. 1 yields a cross section of 25 ± 10 μb for D production with 400-GeV/c protons. (The prompt-lepton experiments are sensitive to the D-production cross section. Here a semileptonic branching ratio of 7.5% is assumed for D's.) If we assume that the cross section for 200-GeV/c pions is about the same as for 400-GeV/c protons, and that the ratio $D^{*+}/(D^+ + D^0)$ is 0.30 ± 0.05 (if one assumes that relative direct production of D^* and D follows $2J+1$ weighting, the ratio is 0.35; if an equal amount of D^* and D^0 is directly produced, the ratio after decay is 0.25), we expect 7.5 ± 3.0 μb for the D^* cross section (average of D^{*+} and D^{*-}). Our result of 4.2 ± 1.4 μb is consistent with this range.

Dip Movement in $p\bar{p}$ and pp Elastic Collisions

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It is pointed out that the recently discovered dip in elastic $p\bar{p}$ cross section is related to the dips at lower $|t|$ and lower energies, consistent with the geometrical picture of high-energy scattering. At 30 GeV/c incoming energy, the dip is predicted by interpolation to occur at $-t = 1.1$ (GeV/c)^2. The curve for dip position versus σ_T is discussed.

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Recently[1] a dip in the angular distribution in elastic $p\bar{p}$ scattering was discovered in a SPS (Super Proton Synchrotron) experiment at CERN. Figure 1 of Ref. 1, which reports on this experiment, is reproduced below. The authors remarked that this dip "is possibly of the same origin as the one seen in pp scattering at a similar t value and the same value of the total cross section (44 mb)." We agree with this assessment. We wish to comment further on $p\bar{p}$ and pp elastic scattering as follows.

(a) That pp and $p\bar{p}$ elastic scattering should be similar at high energies is *natural* in the geometrical picture.[2] The curve in Fig. 1 is a plot of the experimental data for pp elastic scattering at 62 GeV center-of-mass energy.[4] The close agreement is striking. Furthermore, the pp curve is in agreement[5] with the predictions of the geometrical picture.

(b) It was remarked in Ref. 1 that if one tries to associate the dip at 1.4 (GeV/c)^2 with the structure observed at lower energies around $-t \simeq 2.0$ (GeV/c)^2, one finds that the dip moves toward smaller $|t|$ while the total cross section decreases. We point out here that in the geometrical picture[4-6] it would be natural to associate the dip instead with the observed structures at $-t \simeq 0.5$–0.8 (GeV/c)^2 for the data[2a-2i] at 2, 2.7, 3.67, 5, 6.2, 8, 10.1, 10.4, and 16 GeV/c. The dip positions at these energies are plotted in Fig. 2 against the total cross section σ_T, and compared with (1) the experimental dip position[3,7] for pp scattering at the CERN intersecting storage rings (ISR), and (2) the theoretical dip-position curves predicted for pure geometrical scattering.[5] These curves are computed with use of formulas (1) and (2) of Ref. 5, which contain no other input than the geometrical shape of the proton derived from ep scattering (and the total cross section σ_T).

It is clear to us that all the dips in pp and $p\bar{p}$ elastic scattering plotted in Fig. 2 are manifestations of the dip computed for pure geometrical scattering. They are not in perfect agreement with the computed curves because of remnants of low-energy effects which are expected to disappear at very high energies.

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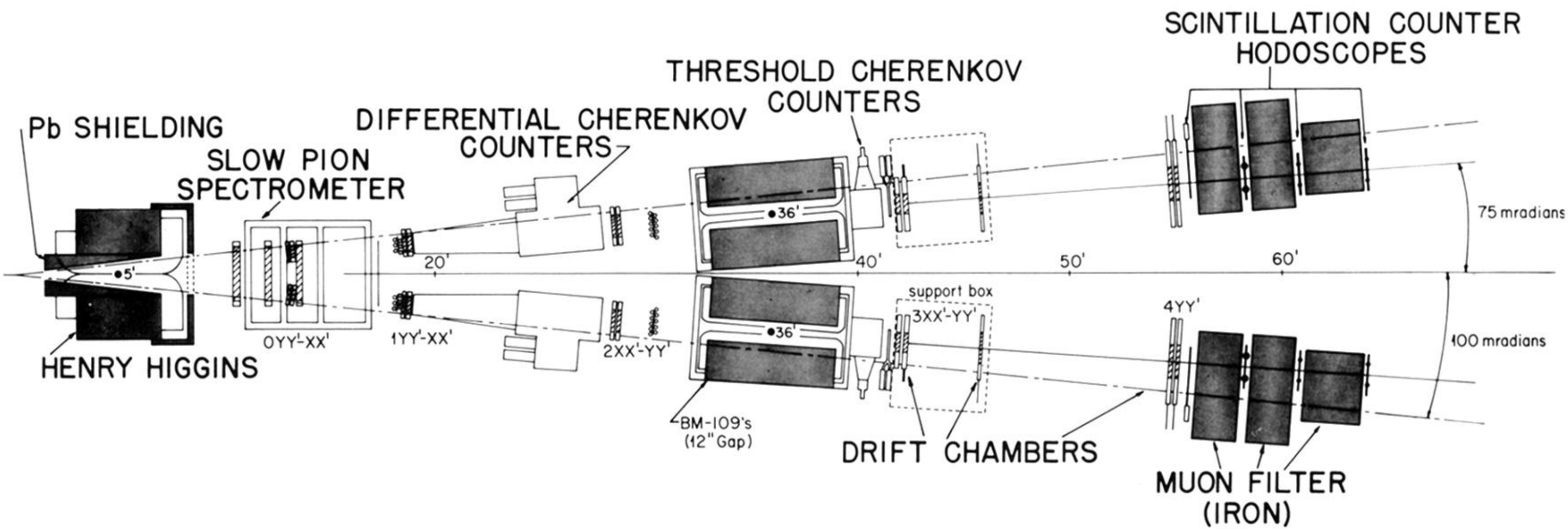

FIG. 1. Plan view of the apparatus.