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Brief Reports

Brief Reports are short papers which report on completed research which, while meeting the usual **Physical Review** *standards of scientific quality, does not warrant a regular article. (Addenda to papers previously published in the* **Physical Review** *by the same authors are included in Brief Reports.) A Brief Report may be no longer than 3½ printed pages and must be accompanied by an abstract. The same publication schedule as for regular articles is followed, and page proofs are sent to authors.*

Search for D^* production in pion-nucleon interactions

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Results are presented of a measurement of the production of D^{*+} (D^{*-}) in 250-GeV/c π^-N interactions. We observe 2.1 ± 7.8 events corresponding to a charged-D^* cross section $\sigma(D^*)$ of 0.4 ± 1.5 μb/nucleon. When averaged with our previous measurement made at 200 GeV/c, the result is $\sigma(D^*) = 2.3 \pm 1.0$ μb/nucleon with $(d\sigma/dx)|_{x=0} = 4.6 \pm 2.0$ μb.

Nine years after the discovery of the charm quark, the study of the production of charmed states in hadronic collisions continues to be a confusing, even controversial subject. This situation exists despite the high absolute rate of charm production. The large backgrounds coming from the total inelastic cross section, as well as the combinatorial background introduced by the high average multiplicities produced in hadron collisions, make unambiguous observations of charmed states in invariant-mass plots a very difficult enterprise. The uncertainties present in prompt-lepton experiments, where the charm signal is inferred from what is not explained as arising from other sources, and in visual experiments, where charmed particles are tagged by their relatively long lifetimes, are hardly less daunting.

The experimental literature has not yet arrived at a consensus on several points.[1] Comparisons of data from the CERN Intersecting Storage Rings (ISR) with data taken at the CERN SPS and Fermilab fixed-target machines indicate a rise in the total charm cross section by more than an order of magnitude in an energy domain well above the charm threshold. This rise is not reflected in the $\sqrt{s}$ dependence of J/ψ production. Several experiments report charm signals implying total cross sections much higher than the averages at the same energy.[2] There is uncertainty over the dependence of the production cross section on the atomic mass number of the target. An analysis of dilepton production data in pp collisions at both the SPS and the ISR indicates upper limits on charm production that are well below reported results of direct measurements.[3]

Other complications arise in the extrapolation of the total charm cross section from a measurement of a single state in a single kinematic domain. Experiments disagree on the x_f distribution of the charm particles, that is, the relative amount of forward versus central production. It is not known whether $\Lambda_c\bar{D}$ or $D\bar{D}$ production is the dominant mechanism or how that may depend on whether a baryon or meson beam is being used, nor is it clear what fraction of the D-meson production is D^*. There is still no convergence of opinion on what the values of various branching fractions of the D-meson decays are.

In view of this situation, we thought it would be worthwhile to add to our previously reported measurement[4] of D^{*+} in 200-GeV/c π^-N interactions at Fermilab the results of additional running at a beam momentum of 250 GeV/c.

The experiment was designed to measure charged-D^* production by observing all the products of the decay chain: $D^{*+} \rightarrow D^0\pi^+$, $D^0 \rightarrow \pi^+K^-$ (and its charge conjugate). An attractive feature of this decay mode is the low Q value, 5.7 MeV, of the D^* two-body decay. In the D^* center-of-mass frame, the cascade pion is emitted essentially at rest, leaving only a small region of phase space in which pions from the background can compete with the signal.

The apparatus was constructed to accept D^*'s produced near $x_f = 0$. It comprised two double-arm spectrometers. The forward spectrometer was used to detect the $K\pi$ pair from the D^0 decay with each particle having an average momentum of about 12 GeV. Two smaller spectrometer arms were used to detect the 1–3-GeV/c pions from the $D^* \rightarrow D^0\pi$ which were swept out of the beam by a magnet just downstream of the target.

Several small modifications were made to the apparatus since the original data taking in order to improve selection and to increase the resolution. Extra drift chambers, positioned closer to the vertex, were added in all the arms. The target was segmented along the beam axis in vertical slices. A matrix was added to the trigger to correlate combinations of hodoscope signals in the two fast arms so as to reject low mass pairs. The memory buffer in the data acquisition system was doubled allowing a total of 96 events to be written per beam spill. Isobutane replaced freon in the differential Cherenkov counter to cut down on multiple scattering, and the counter itself was used in the differential mode for the first time increasing the domain over which we could separate kaons from protons.

As a result of these modifications, the resolution at the D^0 mass went to $\delta M = \pm 12$ MeV from the original $\delta M = \pm 14$ MeV. The resolution in the Q value of the $D^{*+} \rightarrow D^0\pi^-$ went to an average of $\delta Q = \pm 0.6$ MeV from $\delta Q = \pm 0.7$ MeV. The improvements in trigger efficiency allowed us to reach a sensitivity comparable to the original sample in a much shorter running time.

After track reconstruction and particle identification were performed, the analysis proceeded in the search for excesses in a scatter plot of πK pair mass versus the Q value associated with the slow arm pion. The data were summed over both charge signs. We found no significant enhancement in the region of the D^*, even after scanning above and below the expected values to compensate for any systematic error-induced shift. The value we take for our measurement is based on the average of the number of events found in Gaussians fitted to the distribution of events in slices of the scatter plot at the known D^0 mass and D^* decay Q value. The widths of the Gaussians and the slices were determined by our resolution. The result is a net excess of two events over a background of 61 events.

If we assume a production model with $d\sigma/dx \sim (1-|x|)^3$ and take branching ratios of 0.6 and 0.03 for the decays $D^{*+} \rightarrow D^0\pi^+$ and $D^0 \rightarrow \pi^+K^-$, respectively, the result of the new running is

$$\sigma(D^*) = \tfrac{1}{2}[\sigma(D^{*+}) + \sigma(D^{*-})] = 0.4 \pm 1.5\ \mu\text{b/nucleon}\ ,$$

with $(d\sigma/dx)|_{x=0} = 0.8 \pm 2.9$ μb/nucleon. Recall that our original result, taken at a beam momentum of 200 GeV/c, was

$$\sigma(D^*) = 4.2 \pm 1.4\ \mu\text{b/nucleon}\ ,$$

where the error does not include a 30% uncertainty in the normalization. The two measurements are 1.6 standard deviations apart, and there is no reason to discount either. Neglecting the energy dependence of the cross section, the average of these two independent measurements is our final result:

$$\sigma(D^*) = 2.3 \pm 1.0(\pm 0.7)\ \mu\text{b/nucleon}\ .$$

The first error is statistical, the second is the systematic error in the normalization. This corresponds to a differential cross section $d\sigma/dx = 4.6 \pm 2.0$ μb/nucleon at $x = 0$, which is insensitive to the x dependence assumed.

Two experiments at CERN have measured D production in πN interactions. The Amsterdam-Bristol-CERN-Cracow-Munich-Rutherford (ACCMOR) Collaboration, experiment NA11, report $\sigma(D\bar{D}) = 45 \pm 15$ μb/nucleon for 175 and 200 GeV/c π^- on a Be target, with an additional 50% normalization error.[5] They also measure $\sigma(D\bar{D})/\sigma(D^*) \simeq 4$ and find an x dependence $d\sigma/dx \sim (1-|x|)^n$ with $n = 0.8 \pm 0.4$.[6] Combining these numbers gives for D^* production at $x = 0$ $d\sigma/dx = 10 \pm 4$ μb/nucleon. The LEBC-EHS collaboration measures a cross section $\sigma(D^0) = 7.7^{+7.2}_{-3.5}$ μb for $x > 0$, which is insensitive to the x dependence.[7] Assuming a ratio $D^{*+}/D^0 = 0.4$, consistent with Ref. 6, and $n = 0.8$, one gets $d\sigma/dx = 5.5^{+5}_{-3}$ μb. Because of relative normalization problems and differences in detected states and kinematic regions, the experimental cross sections can only be compared to a factor of 2. The present result does confirm that there is not a large central component to the D^* cross section near $x = 0$.

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[1] For a more detailed discussion of several of the points mentioned here, see S. Reucroft, CERN/EP Report No. 83-155, 1983 (unpublished).

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