potential shape (due to diffusion mixing at the Al-Cu boundaries) would result in changes of level position and width, but not in reduced resonance amplitudes. Thus, a slight blurring of the potential boundaries by ~80 Å would eliminate the small mismatch (by 2%) of theoretical and experimental level spacings in Fig. 3. A variation in layer thickness of ~3% is, however, insufficient to account for the reduced resonance amplitudes. Microscopic density fluctuations of surface microroughness would give rise to disorder scattering and, consequently, coherent-beam attenuation, similar to "absorption" (including nuclear capture and thermal inelastic scattering). Calculation shows that an enhancement of "absorption" in pure Al by a factor of $\sim 10^2-10^3$ could explain the data, but such strong scattering is unlikely to exist.

The optical analog of the double-hump potential barrier is the well-known Fabry-Perot interferometer. Thus, the present results indicate that a neutron Fabry-Perot interferometer with a resolution of 10^{-9} eV is feasible.

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High-Energy Photoproduction of the D^{*+}

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Photoproduction of the D^{*+} have been observed where the D^{*+} decays via $D^{*+}\to\pi^+D^0$ and the D^0 decays via $K^-\pi^+$ and $K_s\pi^+\pi^-$. The D^{*+}, D^0 mass difference and the D^0 mass observed here are in excellent agreement with previous measurements of charmed mesons produced in e^+e^- annihilations. The photoproduced D^{*+} and D^{*-} signals are produced nearly equally at the level of about 100 nb/nucleon.

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We report on the observation of the D^{*+} (D^{*-}) produced in the wideband neutral beam at Fermilab. Both this beam and our detector have been described in a previous Letter.[1] Our exposure consisted of approximately 6×10^{11} photons with an energy greater than 50 GeV incident on a 2-cm-long scintillator target. The particles emerging from these interactions were analyzed by a large-acceptance magnetic spectrometer system (multiwire proportional chambers) which includes two multicell Cherenkov counters with pion threholds of 6 and 12 GeV, a large lead-glass array for neutral detection, and a hadron calorimeter. The data described here were recorded under a trigger requiring at least 3 tracks in the spectrometer and a minimum energy deposition of 75 GeV in the hadron calorimeter. A nonnegligible number of events collected under this trigger are K_l or neutron induced rather than photon induced; approximately 25% of the data were taken with 6 radiation lengths of lead inserted into the neutral beam in order to measure the contribution of this hadronic background.

Within a range of momentum from 6 to 22 GeV/c, charged kaons and protons are separable from pions, while kaons are separable from protons and pions in the momentum range from 22 to 44 GeV/c. For the purposes of this Letter, charged-kaon candidates are only required to be unambiguous with pions and thus can lie in the full momentum range from 6 to 44 GeV/c. K_s candidates are selected from two track V^0 candidates with vertices downstream of the target but with a momentum vector which intersects the overall interaction vertex. In order to reduce the Λ^0 contamination we require the reconstructed V^0 mass to lie within 15 MeV/c^2 of the K_s mass, and require that the track with the larger momentum is inconsistent with being a proton or antiproton. Our absolute mass scale is determined by calibrating the J/ψ, K_s, and Λ^0 to their known masses.

In a previous Letter[1] we reported on the observation of D^0 ($\bar{D}^0$) mesons decaying into $K\pi$, observed among 520 000 events which contain both a K^+ and K^- candidate. In an effort to study the photoproduction of charmed mesons in a more inclusive and model-independent way, we have analyzed 9.8×10^6 events containing at least one charged kaon or K_s candidate. In order to avoid unwieldy notation in the discussion which follows, reference to a given state will always imply a reference to its charge conjugate.

The advantages in searching for the D^{*+} pionic cascade with the D^{*+}, D^0 mass difference variable rather than the D^{*+} mass are illustrated in Ref. 2. Figure shows the $M_{K^-\pi^+\pi^+} - M_{K^-\pi^+}$ mass difference distribution obtained in our data for all $K^-\pi^+\pi^+$ combinations with [Fig. 1(a)] $1.800 < M_{K^-\pi^+} < 1.825$ GeV/c^2, [Fig. 1(b)] $1.850 < M_{K^-\pi^+} < 1.875$ GeV/c^2, and [Fig. 1(c)] $1.900 < M_{K^-\pi^+} < 1.925$ GeV/c^2. The only requirement for a combination's entry into Fig. 1 is that the kaon must be identified by the Cherenkov system. A clear enhancement is observed at a mass difference of about 0.1455 GeV for events with $1.850 < M_{K^-\pi^+} < 1.875$ GeV/c^2. We attribute this enhancement to the process $D^{*+} \to \pi^+ D^0 \to \pi^+ K^- \pi^+$, where the $K^-\pi^+$ invariant mass is consistent with the known D^0 mass of 1.863 GeV/c^2. The position of the mass-difference peak is found to be in excellent agreement with the observed $M_{D^{*+}} - M_{D^0}$ of 0.1453 ± 0.0005 GeV/c^2 measured by Feldman, *et al.*,[2] while the width of the peak is consistent with our experimental resolution.

The shaded portions of Fig. 1 show the appro-

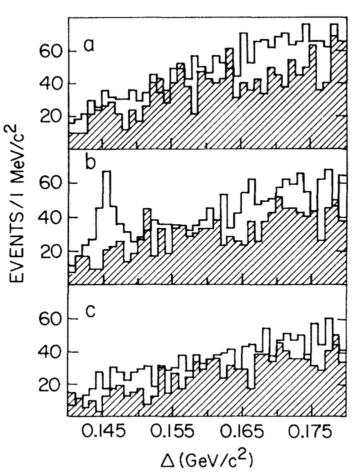

FIG. 1. Mass-difference distributions ($\Delta \equiv M_{K^\mp\pi^\pm\pi^\pm} - M_{K^\mp\pi^\pm}$) for combinations satisfying (a) $1.800 < M_{K^\mp\pi^\pm} < 1.825$ GeV/c^2, (b) $1.850 < M_{K^\mp\pi^\pm} < 1.875$ GeV/c^2, and (c) $1.900 < M_{K^\mp\pi^\pm} < 1.925$ GeV/c^2. The shaded distribution shows the Δ distribution obtained for K_l-minus-neutron background runs. We have multiplied the background by 2.35 to normalize the flux to the photon runs.

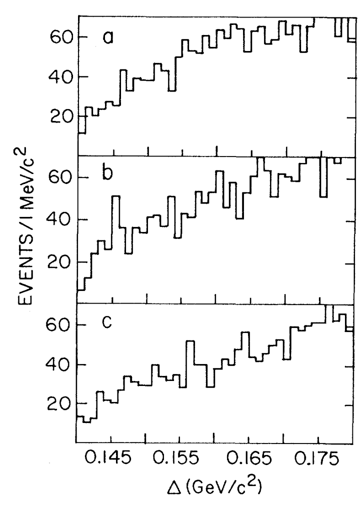

FIG. 2. Mass-difference distribution ($\Delta \equiv M_{K_s\pi^+\pi^-\pi^\mp} - M_{K_s\pi^+\pi^-}$) for combinations satisfying (a) $1.800 < M_{K_s\pi^+\pi^-} < 1.825$ GeV/c^2, (b) $1.850 < M_{K_s\pi^+\pi^-} < 1.875$ GeV/c^2, and (c) $1.900 < M_{K_s\pi^+\pi^-} < 1.925$ GeV/c^2.

priately normalized mass-difference distributions obtained in the K_l-minus-neutron background runs. The absence of any enhancement in the shaded portion of Fig. 1(b) demonstrates that the D^{*+} signal is predominately photoproduced.

Figure 2 repeats this exercise for the decay sequence $D^{*+} \to \pi^+ D^0 \to \pi^+ K_s \pi^+ \pi^-$. Because of the larger combinatoric background for this signal, we only include events with less than eight visible tracks. Again, there appears to be a narrow enhancement at a mass difference of 0.1455 GeV/c^2 for those events with $M_{K_s \pi^+ \pi^-}$ consistent with the mass of the D^0. Figure 3 shows the $K^-\pi^+$ [Fig. 3(a)] and $K_s \pi^+ \pi^-$ [Fig. 3(b)] invariant-mass distributions for combinations within the $D^{*+} - D^0$ mass-difference peak. The curves drawn on Fig. 3 are fits to these mass spectra consisting of a Gaussian signal peak over a smooth exponentially falling background. The fit finds 143 ± 20 signal events at a mass of 1.860 ± 0.002 GeV/c^2 and a width of $\sigma = 0.010 \pm 0.002$ GeV/c^2 for the $K^-\pi^+$ signal of Fig. 3(a), and 35 ± 13 signal events at a mass of 1.869 ± 0.004 GeV/c^2 and a width of $\sigma = 0.012 \pm 0.003$ GeV/c^2 for the $K_s \pi^+ \pi^-$ signal of Fig. 3(b). Both signals have a width comparable to our experimental mass resolutions. The mass centroids are in good agreement with the previously measured D^0 mass of 1.8633 ± 0.0009 GeV.[3] We estimate that systematic mass-scale shifts for the D^0 signal should be less than 5 MeV/c.[2]

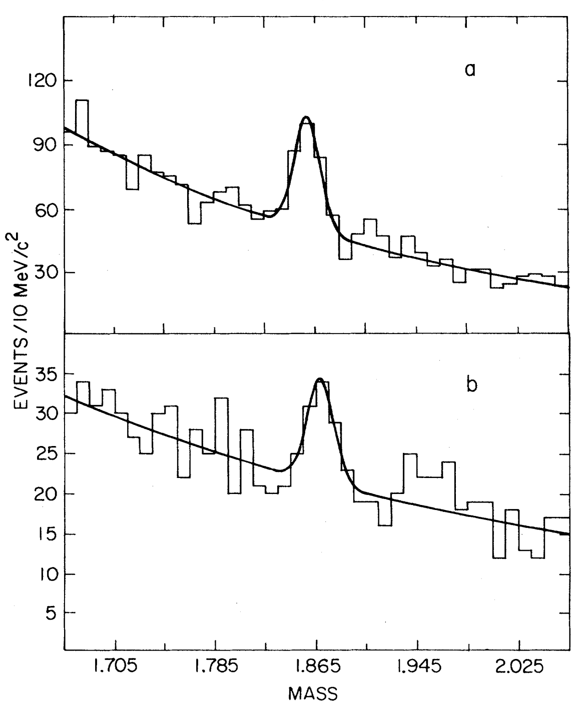

FIG. 3. (a) $K^{\mp}\pi^{\pm}$ invariant-mass distribution for combinations satisfying $0.1425 < \Delta < 0.148$ GeV/c^2, (b) $K_s \pi^+ \pi^-$ invariant-mass distribution for combinations satisfying $0.1445 < \Delta < 0.1465$ GeV/c^2.

In addition to studying the $(K^-\pi^+)\pi^+$ channel as discussed above, we have looked for enhancements in the nonexotic $(K^+\pi^-)\pi^+$ channel. An enhancement in the $M_{K^+\pi^-\pi^+} - M_{K^+\pi^-}$ mass-difference distribution near 0.1455 GeV/c^2 could arise from the conjectured D^0-$\bar{D}^0$ mixing process,[2] or the presence of $\Delta C = -\Delta S$ double-Cabibbo-suppressed decays. No enhancement was observed in the nonexotic channel, thus allowing us to conclude that the fraction of times that a D^0 decays into a K via $K^+\pi^-$ rather than $K^-\pi^+$ is less than 11% (90% confidence limits), which can be compared to the 16% upper limit quoted in Ref. 2.

We find that the ratio of photoproduced D^{*+} to D^{*-} signal events is 1.4 ± 0.4. From this observation we conclude that D mesons are predominantly produced in pairs in our data. Figure 4 shows some measured inclusive properties of our D^{*+} signal which bear on its production mechanism. The data points and error bars of Fig. 4 are obtained by fitting the $K\pi$ invariant-mass spectrum (subject to cuts on the $D^{*+} - D^0$ mass difference) for every bin in the given inclusive plot. The plots have not been corrected for variations in the D^{*+} detection efficiency.

Figure 4(a) shows that the bulk of the D^{*+} signal appears in events with a total visible (charged and neutral) energy of 75 to 100 GeV. The falloff of this distribution at low energies can be explained by acceptance considerations while the high-energy falloff partially reflects our steeply falling photon spectrum.[1] Figure 4(b) showing the fraction of total visible energy carried by the D^{*+} shows that the majority of D^{*+} events are consistent with having $\simeq \frac{1}{2}$ of the visible beam energy, while Fig. 4(c) shows that the bulk of the signal is observed to have a P_t^2 of less than 1 GeV^2/c^2.

We see that the data appear consistent with models where the D^{*+} is produced in association with another D or D^* via the decay of a diffractively photoproduced, low-mass (4 to 5 GeV/c^2) parent. We have used such a model to estimate the spectrum-averaged total D^{*+} inclusive photoproduced cross section for photons over 50 GeV. We assume that the cross section is independent of energy above 50 GeV and that the recoil D or D^* decays isotropically via either of two statistical models,[4] constrained to roughly reproduce the observed multiplicities of D decays. Varying the

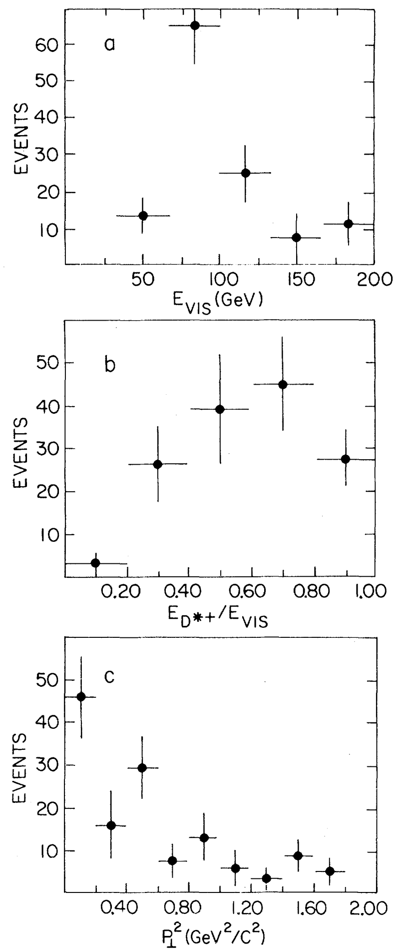

FIG. 4. Inclusive properties of the photoproduced $D^{*\pm}$ signal. These distributions are uncorrected for variations in acceptance. $E_{\rm vis}$ is the sum of the visible charged and neutral energy seen in our apparatus.

parameters of our model within the limits imposed by the data of Fig. 4 changes the acceptance by less than 10%. Based on the 6% average detection and trigger efficiency obtained in this model, we find that

$$\sigma_{\gamma p \to D^{*}+X} \frac{\Gamma(D^{*+}\to\pi^+D^0)}{\Gamma(D^{*+}\to{\rm all})}\,\frac{\Gamma(D^0\to K^-\pi^+)}{\Gamma(D^0\to{\rm all})}$$

$$= 1.8 \pm 0.6 \text{ nb/nucleon},$$

where we have assumed a linear A dependence for the nuclear correction. Using the measured values[3,5] of 0.60 ± 0.15 and 0.026 ± 0.004 for the $D^{*+} \to \pi^+D^0$ and $D^0 \to K^-\pi^+$ branching ratios, we conclude that $\sigma_{\gamma p \to D^* + X} = 118 \pm 49$ nb/nucleon. The ratio of the $D^0 \to \overline{K}_0\pi^+\pi^-$ to the $D^0 \to K^-\pi^+$ branching ratio is found to be 1.7 ± 0.8 in our data compared to 1.15 ± 0.3, the value presented in Ref. 6.

Finally we estimate the fraction of D^0 events arising from D^{*+} pionic cascades. A fit to the completely inclusive $K^-\pi^+$ invariant-mass spectrum (not shown) reveals an ≈3-standard-deviation excess of 660 ± 230 events over a background of ≈33 000 events at the D^0 mass. This would represent an inclusive D^0 cross section of 295 $\pm$ 130 nb/nucleon, in good agreement with Ref. 1, and indicates that $0.24^{+0.13}_{-0.06}$ of photoproduced D^0's come from $D^{*+} \to \pi^+D^0$.[7]

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