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D. J. Summers, V. K. Bharadwaj, B. H. Denby, A. M. Eisner, R. G. Kennett,
A. Lu, R. J. Morrison, M. S. Witherell, and S. J. Yellin
University of California, Santa Barbara
Santa Barbara, California 93106, USA

P. Estabrooks and J. Pinfold
Carleton University, Ottawa K1S 5B6, Canada

D. F. Bartlett, S. Bhadra, A. L. Duncan, J. R. Elliott, and U. Nauenberg
University of Colorado, Boulder, Colorado 80309, USA

J. A. Appel, J. Biel, D. Bintinger, J. Bronstein, C. Daum, P. M. Mantsch,
T. Nash, W. Schmidke, K. Sliwa, M. D. Sokoloff, K. C. Stanfield,
M. Streetman, and S. E. Willis
Fermi National Accelerator Laboratory, Batavia, Illinois 60510, USA

M. J. Losty
National Research Council of Canada, Ottawa, Ontario K1A OR6, Canada

G. R. Kalbfleisch, and M. Robertson
University of Oklahoma, Norman, Oklahoma 73019, USA

and

D. E. Blodgett, S. B. Bracker, G. F. Hartner, B. R. Kumar, G. J. Luste,
J. F. Martin, K. K. Shahbazian, R. A. Sheperd, W. J. Spalding, and C. J. Zorn
University of Toronto, Toronto M5S 1A7, Canada

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D.J. Summers, V.K. Bharadwaj,[a] B.H. Denby, A.M. Eisner,[b] R.G. Kennett,[c]
A. Lu, R.J. Morrison, M.S. Witherell, S.J. Yellin
University of California, Santa Barbara
Santa Barbara, California 93106

P. Estabrooks, J. Pinfold
Carleton University, Ottawa K1S 5B6, Canada

D.F. Bartlett, S. Bhadra, A.L. Duncan,[d] J.R. Elliott, U. Nauenberg
University of Colorado, Boulder, Colorado 80309

J.A. Appel, J. Biel,[e] D. Bintinger,[f] J. Bronstein,[e] C. Daum,[g]
P.M. Mantsch, T. Nash, W. Schmidke[h] K. Sliwa, M.D. Sokoloff,
K.C. Stanfield, M. Streetman, S.E. Willis[i]
Fermi National Accelerator Laboratory
Batavia, Illinois 60510

M.J. Losty
National Research Council of Canada
Ottawa, Ontario K1A 0R6, Canada

G.R. Kalbfleisch, M. Robertson[j]
University of Oklahoma, Norman, Oklahoma 73019

D.E. Blodgett, S.B. Bracker, G.F. Hartner, B.R. Kumar, G.J. Luste
J.F. Martin, K.K. Shahbazian, R.A. Sheperd, W.J. Spalding,[k] C.J. Zorn
University of Toronto, Toronto M5S 1A7, Canada

A B S T R A C T

Results are presented from an experiment observing photoproduction of the D^* at an average energy of 103 GeV. Clean signals are seen for the decay $D^{*\pm} \rightarrow \pi^{\pm} D^{\circ}$ with the D° decaying into both $K^{\mp}\pi^{\pm}$ and $K^{\mp}\pi^{\pm}\pi^{\circ}$. Analysis of the Dalitz plot for the $K\pi\pi$ mode gives branching fractions for $K^{-}\rho^{+}$, $K^{*-}\pi^{+}$, and $\overline{K}^{*\circ}\pi^{\circ}$ final states. The observed branching fraction for $D^{\circ} \rightarrow K^{-}\rho^{+}$, which is much lower than a previous result, is in approximate agreement with the value expected for an $I = 1/2$ final state.

The nonleptonic weak decays of the charmed mesons have been the subject of much experimental and theoretical effort. One important question is whether the branching ratios for the various two-body and quasi-two-body states ($K\pi$, $K\rho$, and $K^*\pi$) are consistent with an $I = 1/2$ final state, which is expected if the D° decay is dominated by W exchange.[1] We report the results of an experiment using the Tagged Photon Spectrometer at Fermilab which observed the decay $D^{*+} \to \pi^+ D^\circ$ with the D° decaying into both $K^-\pi^+$ and $K^-\pi^+\pi^\circ$. (The charge conjugate states are implicitly included in all decay modes.) The $K^-\pi^+\pi^\circ$ sample represents the largest reported to date, and it was used to measure the branching ratio for the $K\rho$ and $K^*\pi$ modes, as well as that for non-resonant $K^-\pi^+\pi^\circ$ decay.

The D^* events were produced by tagged photons of energy between 60 and 160 GeV, generated by a 170 GeV electron beam in a 0.2 radiation length copper radiator. The tagged photons impinged on a 1.5 meter liquid hydrogen target, which was placed at the front end of the spectrometer shown in Figure 1.[2] The low-level trigger required the detection of at least 30% of the tagged photon energy in the downstream calorimeters. Recoil protons were measured and identified by three layers of MWPC and four layers of scintillation counters in the recoil detector,[3] and the missing mass of the forward state was computed by a very fast data driven processor.[4] The high-level trigger demanded that the recoil system detect either a single proton at the primary vertex with a high missing mass or at least three charged tracks. The forward charged particles were analyzed with drift chambers and two magnets of large aperture, with a momentum resolution for fast tracks of $\frac{\Delta P}{P} = .004 + .0005 \times P$ (GeV/c). Two multi-cell Cherenkov counters identified charged tracks separating pions from kaons in the momentum range 6-36 GeV/c. Photons were detected either in the forward Segmented Liquid Ionization Calorimeter (SLIC)[5] or in smaller counters placed above and below the aperture of the second magnet (Outriggers). Almost all the π°'s from detected D° decays were seen in the SLIC, in which the energy resolution was about $15\%/E^{1/2}$ for photons, and the spatial resolution was a few millimeters. The spectrometer also included a hadronic calorimeter which was used in the trigger and to separate neutral hadrons from photons, and an iron muon filter.

To measure the ratio $B(D^\circ \to K^-\pi^+\pi^\circ)/B(D^\circ \to K^-\pi^+)$ the desired final states are $K^-\pi^+\pi^+$ and $K^-\pi^+\pi^+\pi^\circ$. In each case a cut was applied on the probability that the three charged particles satisfy the $K^-\pi^+\pi^+$ hypothesis. This cut was chosen to minimize the relative systematic error between the two decay modes, although it reduced the number of events used in this analysis. In addition, for the π° sample, a cut was applied on a π° probability calculated from the mass of the two gammas and the background underneath the π° peak. To observe the decay cascade $D^{*+} \to D^\circ\pi^+$, $D^\circ \to K^-\pi^+$, we chose $K^-\pi^+\pi^+$ combinations with $M_{K^-\pi^+}$ less than 60 MeV/c^2 from the D° mass. For such combinations the spectrum of the mass difference, $\Delta M = M_{K\pi\pi} - M_{K\pi}$ has a clear peak at the $D^{*+} - D^\circ$ mass difference. This spectrum gives a good fit to background of the form $aQ^{1/2}(1-bQ)$ (where $Q = \Delta M - M_{\pi^+}$, a and b are constants) plus a Gaussian centered at $\Delta M = 0.1454$ GeV/c^2 and $\sigma = 1.2$ MeV/c^2, with 39 ± 8 events in the peak. A similar analysis was carried out for the $K^-\pi^+\pi^+\pi^\circ$ sample, and the fit to the ΔM plot using the same peak parameters as above yields 41 ± 9 events in the peak.

To determine the branching ratio $B(D^\circ \to K^-\pi^+\pi^\circ)/B(D^\circ \to K^-\pi^+)$, the ratio of the efficiencies for the two modes is needed. Many factors, including the beam flux and spectrum, trigger efficiencies, target size, etc., are common to both modes. The reconstruction efficiency and identification efficiency are the only factors which need to be calculated from Monte Carlo studies.

The only strong difference between the two cases is the probability of reconstructing the π°, which varies with the energy of the π° from a threshold at 4 GeV to a value of approximately 40% at 30 GeV and above. This efficiency was determined by adding to real events photon showers generated by a Monte Carlo program, and processing these events by the usual π°-finding programs. To check this determination we also studied the π° efficiency using the various charge states of the decay $K^* \to K\pi$. A Monte Carlo which used this π° efficiency gave for the ratio of efficiencies $\varepsilon(K^-\pi^+\pi^\circ)/\varepsilon(K^-\pi^+)$ $= 0.25 \pm 0.04$. Using this number and the relative number of events in the two D^* peaks we calculate $B(D^\circ \to K^-\pi^+\pi^\circ)/B(D^\circ \to K^-\pi^+) = 4.3 \pm 1.4$. Combining this with the current average value for the $D^\circ \to K^-\pi^+$ branching ratio, $2.4 \pm 0.4\%$,[6] yields a measurement of $B(D^\circ \to K^-\pi^+\pi^\circ) = 10.3 \pm 3.7\%$.

For the Dalitz plot study, a sample of $K^-\pi^+\pi^+\pi^\circ$ events was chosen with somewhat looser Cherenkov cuts and with $M_{K^-\pi^+\pi^\circ}$ within 50 MeV/c^2 of the D° mass. Figure 2 shows the ΔM spectrum for these events, with a clear peak at $\Delta M = 0.1454$ GeV/c^2. To obtain a clean sample for this analysis the 82 events with ΔM between 0.1440 and 0.1470 GeV/c^2 were selected; a fit to the ΔM spectrum determines the background to be 45% in this region. The Dalitz plot for these events is shown in Fig. 3(a). A high-statistics background sample was constructed by taking events in the D° mass range but with ΔM outside the D^* range. (The D° fraction for these events is small.) The Dalitz plot for this sample, shown in Fig. 3(b), gave a good fit to uniform phase space times an efficiency which depended linearly on $M^2(K^-\pi^+)$, due to the energy dependence of the π° efficiency. We also examined this background for ρ and K^* and found it was consistent with no contribution from these vector mesons. We made a maximum likelihood fit to the Dalitz plot from the D^* region, allowing a flat background with the acceptance correction as for the background, plus resonant contributions from $K^-\rho^+$, $K^{*-}\pi^+$, and $\overline{K}^{*\circ}\pi^\circ$. Each vector meson was described by a Breit-Wigner with the appropriate decay angular distribution. Interference effects are small compared with the quoted errors, and are neglected. The results are shown in Table 1. Only in the $K^-\rho^+$ mode is there evidence of a strong resonant contribution. We note that the $\cos^2\theta$ distribution for the $\rho \to \pi\pi$ decay means that the ρ band is populated primarily at the edges of the Dalitz plot. (Here θ is the angle in the $\pi\pi$ center of mass, with θ=0 along the K^- direction in that frame.) Fig. 4 shows the $M^2(\pi^+\pi^\circ)$ spectrum for events with $|\cos\theta| > 0.5$, a cut which keeps 1/2 of the smooth $\pi\pi$ spectrum but 7/8 of the ρ. Thus this plot projects the region of the Dalitz plot most sensitive to the ρ contribution. The value of $0.31\ ^{+0.20}_{-0.14}$ for the ratio $B(D^\circ\to K^-\rho^+)/B(D^\circ\to K^-\pi^+\pi^\circ)$ compares to the earlier value of $0.85\ ^{+0.11}_{-0.15}$.[1] Combining this fraction with the $B(D^\circ\to K^-\pi^+\pi^\circ)$ ratio above gives a branching ratio $B(D^\circ\to K^-\rho^+) = 3.2\ ^{+2.3}_{-1.8}\%$. The low fractions quoted in Table 1 for the $K^{*-}\pi^+$ and $\overline{K}^{*\circ}\pi^\circ$ contributions agree with the earlier experiment. Branching ratios listed in Table 1 for the $D^\circ\to K^*\pi$ modes take into account the branching ratios for $K^* \to K\pi$ decay.

One of the crucial problems in the study of D decays is to determine whether the dominant mode is one in which the light quark is a spectator, or one in which both the quark and antiquark couple to the weak vertex. If the non-spectator quark decay dominates (W exchange), the D^+ lifetime is longer than the D°, since the only such modes available to the D^+ are Cabibbo-suppressed. The non-spectator diagram leads to an I = 1/2 final state, although an I = 1/2 state does not rule out spectator-quark decay. The I = 1/2 state is characterized by the ratios:

$$\frac{B(D^\circ\to K^-\pi^+)}{B(D^\circ\to \overline{K}^\circ\pi^\circ)} = \frac{B(D^\circ\to K^{*-}\pi^+)}{B(D^\circ\to \overline{K}^{*\circ}\pi^\circ)} = \frac{B(D^\circ\to K^-\rho^+)}{B(D^\circ\to \overline{K}^\circ\rho^\circ)} = 2.$$

Existing data for the first two channels were consistent with the ratio of 2, but the measurements for the last ratio were $B(D^\circ\to K^-\rho^+) = 7.2^{+3.0}_{-3.1}\%$ and $B(D^\circ\to\overline{K}^\circ\rho^\circ) = 0.1^{+0.6}_{-0.1}\%$.[1] The present result, $B(D^\circ\to K^-\rho^+) = 3.2^{+2.3}_{-1.8}\%$ can be compared with twice the measured ratio for $D^\circ \to \overline{K}^\circ\rho^\circ$, or $0.2^{+1.2}_{-0.2}\%$. Thus the present result is in approximate agreement (1.4 standard deviations) with the expectation for a pure I = 1/2 state.

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(a) Present address: University of California, Irvine, California.

(b) Present address: Institute for Research at Particle Accelerators, Palo Alto, California.

(c) Also at: California State University, Northridge, California.

(d) Present address: University of Washington, Seattle, Washington.

(e) Present address: Comavid Corporation, North Aurora, Illinois.

(f) Present address: University of California, San Diego, California.

(g) On sabbatical leave from NIKHEF-H, Amsterdam, Netherlands.

(h) Present address: University of California, Berkeley, California.

(i) Present address: University of Oklahoma, Norman, Oklahoma.

(j) Present address: Bell Laboratories, Holmdel, New Jersey.

(k) Present address: Fermi National Accelerator Laboratory, Batavia, Illinois.

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TABLE I

Contributions to $D^\circ \to K^-\pi^+\pi^\circ$ Decay

Channel	Fraction of $D^\circ \to K^-\pi^+\pi^\circ$ Decays	Branching Ratio
$K^-\rho^+$	$0.31\ ^{+.20}_{-.14}$	$3.2\ ^{+2.3}_{-1.8}\%$
$\overline{K}^{*\circ}\pi^\circ$	$0.06\ ^{+.09}_{-.06}$	$0.9\ ^{+1.4}_{-0.9}\%$
$K^{*-}\pi^+$	$0.11\ ^{+.12}_{-.08}$	$3.4\ ^{+3.9}_{-2.8}\%$
Non-resonant decays	$0.51 \pm .22$	$5.2 \pm 2.9\%$

Table I: Results of the fit to the $D^\circ \to K^-\pi^+\pi^\circ$ Dalitz plot. The category "non-resonant decays" does not include the contribution to the Dalitz plot from background below the D°.

FIGURE CAPTIONS

Figure 1: The Tagged Photon Spectrometer at Fermilab

Figure 2: $\Delta M = M_{K\pi\pi\pi} - M_{K\pi\pi}$ for events with $M_{K^-\pi^+\pi^\circ}$ within 50 MeV/c^2 of the D°. The smooth curve is a fit to the background of the form described in the text.

Figure 3: The Dalitz plot for (a) the D° region and (b) the background sample. The boundary is drawn for the center of the $K^-\pi^+\pi^\circ$ mass range.

Figure 4: $M^2(\pi^+\pi^\circ)$ for events from the $D^\circ \rightarrow K^-\pi^+\pi^\circ$ sample with $|\cos\theta| > 0.5$ for the $\pi^+\pi^\circ$ system. The upper curve shows the result of the fit to the entire Dalitz plot, projected on the $M^2(\pi^+\pi^\circ)$ axis. The lower curve shows the result of the fit with the ρ contribution removed.

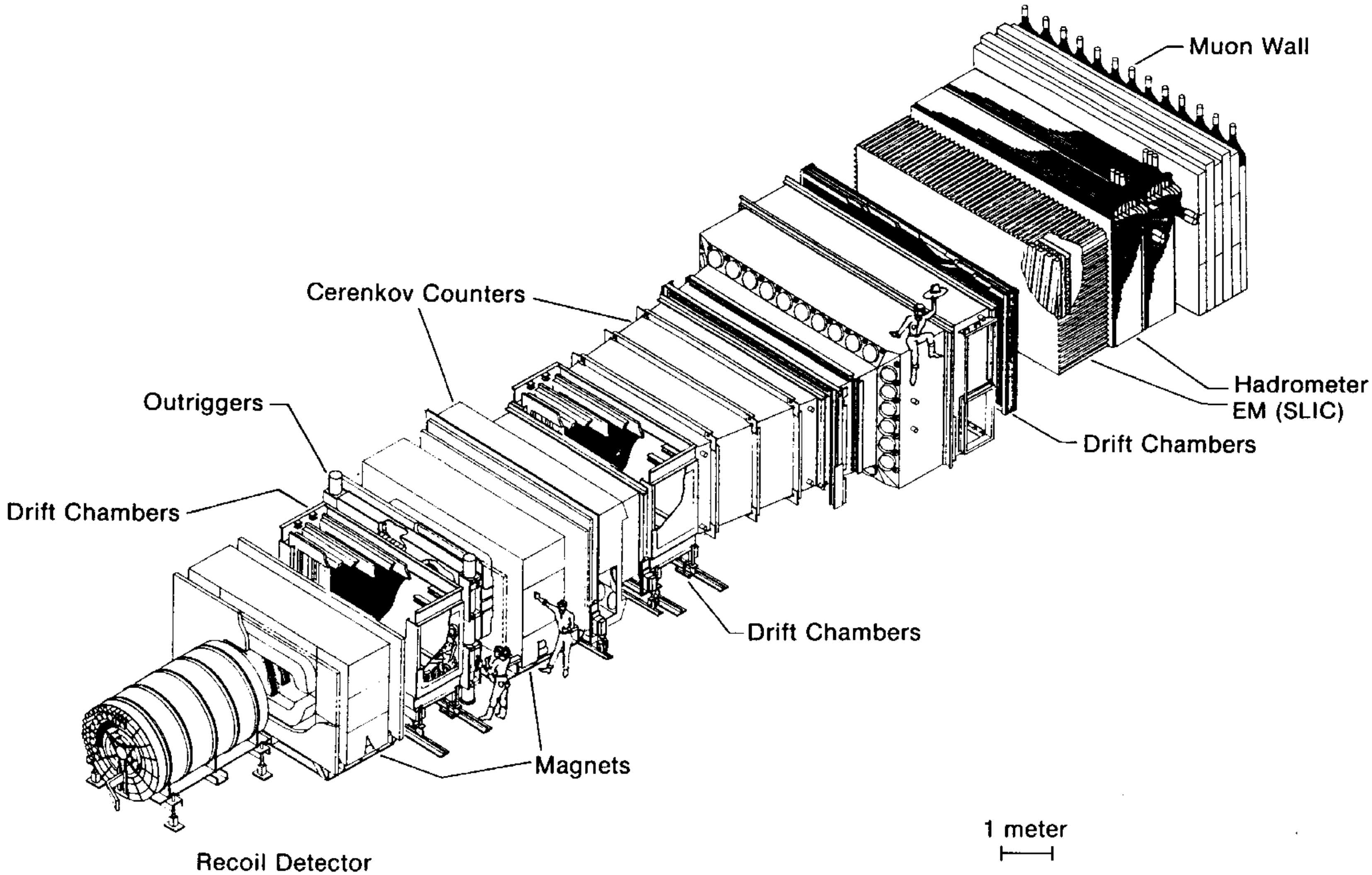
Muon Wall
Hadrometer
EM (SLIC)
Drift Chambers
Cerenkov Counters
Outriggers
Drift Chambers
Drift Chambers
Magnets
Recoil Detector
1 meter

Figure 1

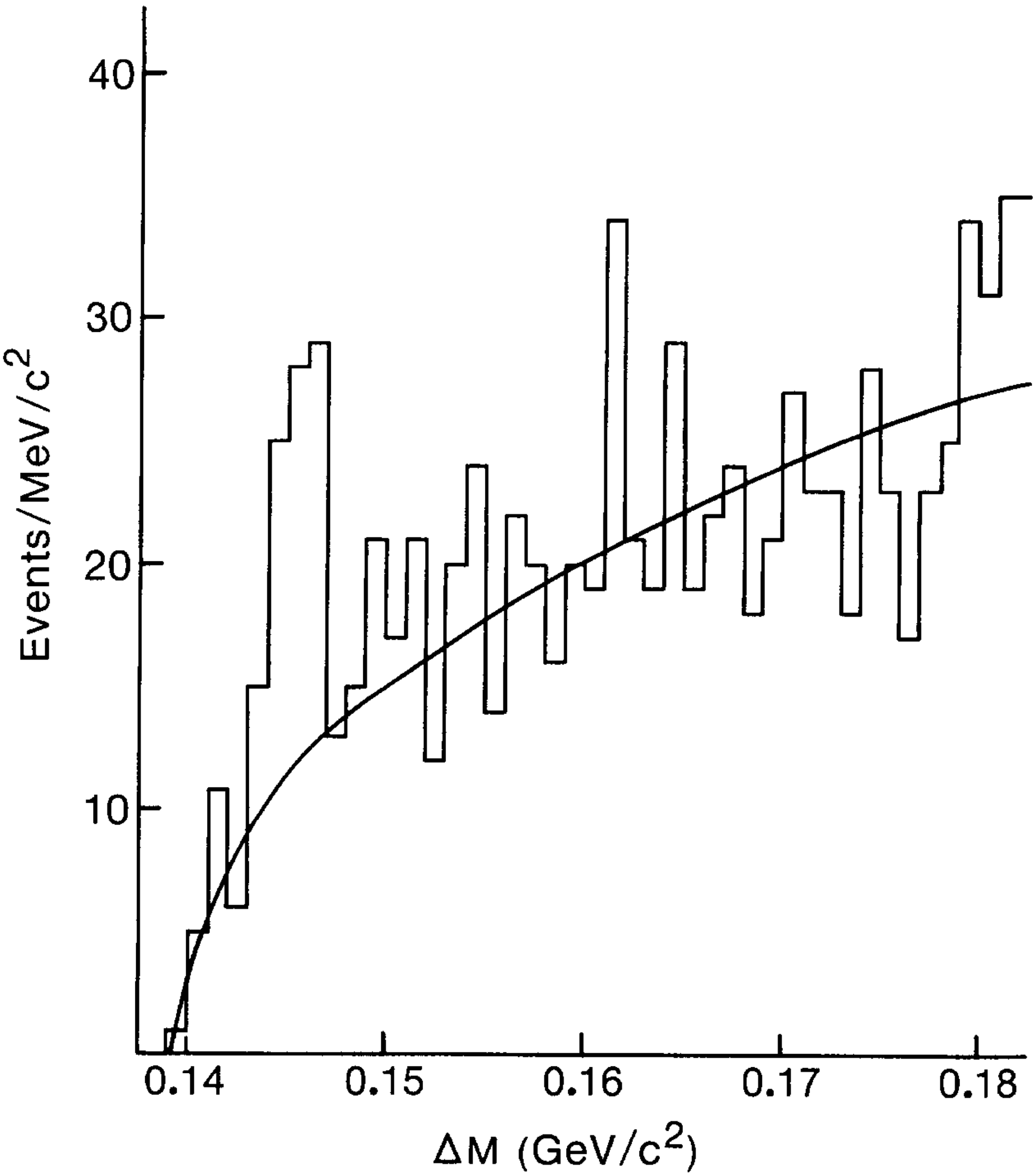

Figure 2

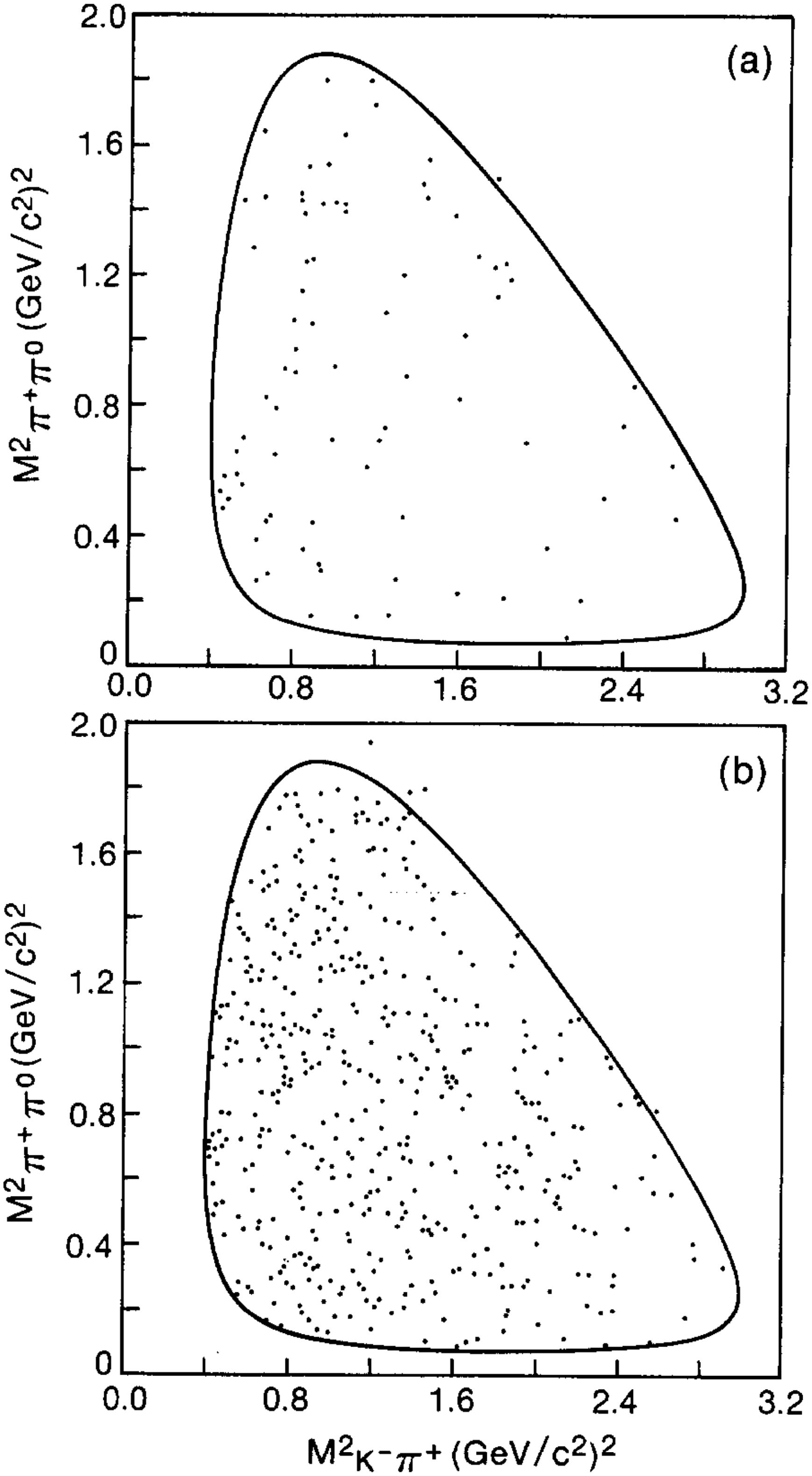

Figure 3

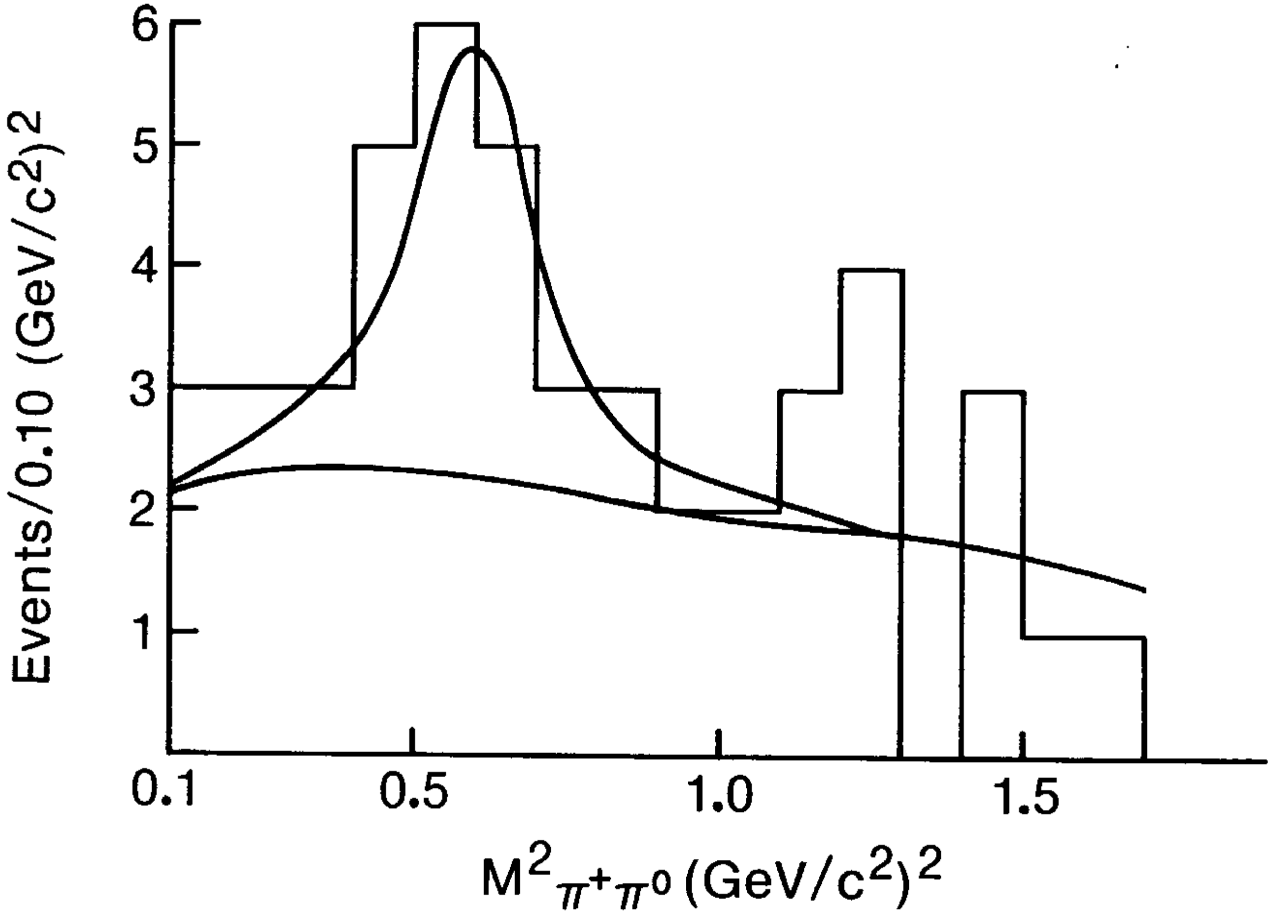

Figure 4