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ERRATUM

Measurement of the D^* Branching Ratios*

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The Mark III Collaboration

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Page 3, in the fourth line of the second paragraph, an asterisk is added so that it reads: "In the case of $D^*\bar{D}^*$, it cannot; it is assumed to be isotropic.[13]"

Page 3, in the first sentence of the third paragraph, the hyphens are removed from "recoil mass squared."

Submitted to *Physics Letters B*

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‡Deceased

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Abstract

We report a new measurement of the D^* branching ratios, using data obtained with the Mark III detector at the e^+e^- storage ring SPEAR at $\sqrt{s} = 4.14$ GeV. A fit to the recoil mass squared spectrum of D mesons reconstructed through the decay modes $K^-\pi^+\pi^+$ and $K^-\pi^+$ is used to extract the $D^{*+} \to \gamma D^+$, $\pi^0 D^+$, $\pi^+ D^0$ and $D^{*0} \to \gamma D^0$, $\pi^0 D^0$ branching ratios.

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The low Q value of the hadronic decay modes of the D^* provides a clean method to identify charm. This method is used to determine charmed meson cross sections above the D^* production threshold, which requires the D^* branching ratios. It is also used to determine B meson branching ratios and cross sections through the decay $B \to D^* + X$. The D^* branching fractions are also interesting as tests of models of charmed vector meson decay.[1-7] Having previously addressed the weak decays of D mesons,[8,9] we now turn to the electromagnetic and strong decays of D^* mesons.

The data, corresponding to an integrated luminosity of 6.3 pb^{-1}, were obtained with the Mark III detector[10] at the e^+e^- storage ring SPEAR at a center-of-mass energy of 4.14 GeV. At this energy, D mesons can be produced either directly or as decay products of D^*'s through the reactions $e^+e^- \to D^*\bar{D}^*, D^*\bar{D}, D\bar{D}$.[11,12] It is assumed that the D^* always decays hadronically or electromagnetically to a D meson, which implies the following constraints on the branching ratios:

$$\begin{aligned} B(D^{*+} \to \pi^+ D^0) + B(D^{*+} \to \pi^0 D^+) + B(D^{*+} \to \gamma D^+) &= 1 \quad \text{and} \\ B(D^{*0} \to \pi^0 D^0) + B(D^{*0} \to \gamma D^0) &= 1\ . \end{aligned} \tag{1}$$

In the analysis, D mesons are reconstructed using the decay modes $K^-\pi^+\pi^+$ and $K^-\pi^+$ and the recoil mass squared spectrum is studied. These channels are selected because they allow good separation of the signal from backgrounds. Kaons are identified by the time-of-flight system; all other charged tracks are assumed to be pions. The D^+ candidates (340 ± 60) and the D^0 candidates (750 ± 40) are selected by requiring the $K^-\pi^+\pi^+$ and $K^-\pi^+$ invariant masses to lie between 1.80 and 1.92 GeV/c^2. The invariant mass distributions are shown in Fig. 1. The recoil mass squared u is defined by $u = (\sqrt{s} - E_D)^2 - P_D^2$. The u distributions for track combinations which satisfy the invariant mass cut are shown in Figs. 2(a) and 3(a).

The shape of the u distribution for D's produced in the decay of D^*'s depends on the momentum of the parent D^* in the lab frame and the angular distribution of the D in the D^* rest frame. In the case of $D^*\bar{D}$, the angular distribution of the D in the D^* frame can be uniquely predicted. In the case of $D^*\bar{D}^*$, it cannot; it is assumed to be isotropic.[13] Initial state radiation further distorts the shape of the u distribution by reducing the effective center-of-mass energy,[14] producing a high mass tail on each structure.

The D^* branching ratios are extracted by fitting the recoil mass squared spectrum using functions which describe the shape of the various contributions to the signal and background. The signal contributions are determined by smoothing Monte Carlo data with interpolating cubic splines. The effects of momentum resolution, detector acceptance, beam-energy fluctuations, and initial-state radiation on the shape of the spectra are thus all taken into account. The individual components of the recoil spectra for each source of D^+ and D^0 are shown in Figs. 2(b) and 3(b). The shape of the u distribution for background events is determined by fitting the recoil mass squared for track combinations with the wrong charge, as shown in Fig. 4.

The u distribution of the signal depends on eleven parameters: five branching ratios of the charged and neutral D^*, and six production cross sections. The number of independent parameters is reduced to five by imposing constraints.

The branching ratios are required to satisfy Eq. (1). It is assumed that the charged and neutral charmed mesons are produced in equal amounts except for P-wave[15] phase space factors[16] due to D^* or D mass differences:

$$\begin{aligned}
\frac{N_{D^{*0}\bar{D}^{*0}}}{N_{D^{*+}D^{*-}}} &= \left(\frac{P_{D^{*0}}}{P_{D^{*+}}}\right)^3 = 1.07 \ , \\
\frac{N_{D^{*0}\bar{D}^{0}}}{N_{D^{*+}D^{-}}} &= \left(\frac{P_{D^{*0}}}{P_{D^{*+}}}\right)^3 = 1.04 \ , \\
\frac{N_{D^{0}\bar{D}^{0}}}{N_{D^{+}D^{-}}} &= \left(\frac{P_{D^{0}}}{P_{D^{+}}}\right)^3 = 1.03 \ .
\end{aligned} \tag{2}$$

Isospin conservation is used to relate the branching ratios of the D^{*+}:

$$\frac{\Gamma(D^{*+} \to \pi^0 D^+)}{\Gamma(D^{*+} \to \pi^+ D^0)} = \frac{1}{2}\left(\frac{P_{D^+}}{P_{D^0}}\right)^3 = 0.46 \ , \tag{3}$$

thus coupling the contributions shown as curves A in Figs. 2(b) and 3(b). Constraint (3) is essential in order to disentangle the contributions to the signal of the D^{*+} and D^{*0} decays to D^0, [curves A and B in Fig. 3(b)] which exhibit considerable overlap.

A binned maximum likelihood fit is simultaneously performed to the charged and neutral D spectra. The numbers of D^+ and D^0 signal events are fitted to be equal to the numbers of signal events in the invariant mass peaks shown in Fig. 1. The result of the fit is shown in Figs. 2 and 3. The χ^2 of the fit is 109 for 120 degrees of freedom. The parameters of this fit are summarized in Tables I, II, and III.

The inclusive cross sections are measured to be $\sigma_{D^+} = 2.3 \pm 0.3 \pm 0.9$ nb and $\sigma_{D^0} = 8.8 \pm 0.8 \pm 3.3$ nb, using the D branching ratios: $B(D^+ \to K^-\pi^+\pi^+) =$

$0.091 \pm 0.013 \pm 0.004$ and $B(D^0 \to K^-\pi^+) = 0.042 \pm 0.004 \pm 0.004$.[9] Removing the constraint on the number of signal events does not significantly change the value of σ_{D^+} and σ_{D^0} derived from the constrained fit, indicating that the background in the exclusive analysis has been correctly parametrized and fitted. The systematic errors include contributions from uncertainties on efficiencies (8%), background parametrization (6%), assumptions on angular distributions (8%), and D branching ratios (6%). The various contributions to the total systematic error have been added in quadrature.

The D^* branching ratios have been previously measured[17-19] using a similar technique. The present determination represents an improvement over previous measurements in that the data sample has higher statistics, the isospin constraint in Eq. (3) has been imposed, the radiative tail of the u distribution has been taken into account, and the model-dependent constraint on the ratio of the radiative decays of the D^{*+} and D^{*0} has been omitted.

Comparison of the measurements of D^* branching ratios with theoretical models are complicated by the fact that these models reliably predict only the radiative (magnetic dipole) widths and that only an upper limit on the total width of the D^* exists.[20] Since the ratio of the hadronic widths of the charged and neutral D^* (Γ_h^+/Γ_h^0) is reliably estimated on the basis of isospin symmetry, we follow Brekke and Rosner[2] to define the quantity,

$$k = \frac{(1 - B_\gamma^+)/(1 - B_\gamma^0)}{B_\gamma^+/B_\gamma^0} = \frac{\Gamma_h^+/\Gamma_h^0}{\Gamma_\gamma^+/\Gamma_\gamma^0} \,, \tag{4}$$

relating the experimentally accessible branching ratio B_γ, to the radiative widths. In this way the predictions of the magnetic dipole widths obtained using the simple quark model[1,2] or various versions of the MIT bag model[3-6] may be compared with the experimentally measured branching ratios (see Table IV). We see that models in which the charm quark magnetic dipole moment is ignored, e.g., the Wilcox[5] MIT bag model, agree best with our measurement. The models of Brekke[2] (the simple quark model), Hackman[3] (the original MIT bag model), and Izatt[4] (a variation of the MIT bag model which treats the heavy quark as nonrelativistic in the center of the bag) agree less well.

Acknowledgement

We gratefully acknowledge the efforts of the SPEAR staff.

Table I. Quasi-two-body production cross sections (nb) for this experiment, and the Mark II experiment.

	$\sigma(D^*\bar{D}^*)$	$\sigma(D^*\bar{D})$	$\sigma(D\bar{D})$
This Experiment	$3.6 \pm 0.2 \pm 0.6$	$1.5 \pm 0.1 \pm 0.3$	$0.23 \pm 0.04 \pm 0.05$
Mark II[19]	4.4 ± 0.7	2.0 ± 0.5	0.4 ± 0.3

Table II. Measured branching ratios of D^{*+}'s. For comparison, the results of previous experiments are also included.

	$B(\gamma D^+)$	$B(\pi^0 D^+)$	$B(\pi^+ D^0)$
This Experiment	$0.17 \pm 0.05 \pm 0.05$	$0.26 \pm 0.02 \pm 0.02$	$0.57 \pm 0.04 \pm 0.04$
Mark II[19]	0.22 ± 0.12	0.34 ± 0.07	0.44 ± 0.10
SLAC-LBL[18]	0.08 ± 0.07	0.28 ± 0.09	0.64 ± 0.11

Table III. Measured branching ratios of D^{*0}'s.

	$B(\gamma D^0)$	$B(\pi^0 D^0)$
This Experiment	$0.37 \pm 0.08 \pm 0.08$	$0.63 \pm 0.08 \pm 0.08$
JADE[21]	$0.53 \pm 0.09 \pm 0.10$	$0.47 \pm 0.09 \pm 0.10$
Mark II[19]	0.47 ± 0.12	0.53 ± 0.12
SLAC-LBL[17]	0.45 ± 0.15	0.55 ± 0.15

Table IV. Comparison of experimental and predicted values of the quantity $k = \frac{\Gamma_h^+/\Gamma_h^0}{\Gamma_\gamma^+/\Gamma_\gamma^0}$.

	This Experiment[22]	Brekke[2]	Hackman[3]	Izatt[4]	Wilcox[5]
k	3^{+3+3}_{-1-2} (< 17 at 95% C.L.)	16	59	42	9

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12. In this analysis it is assumed that nonresonant production, e.g., $D\bar{D}\pi$, does not occur at this low energy. An upper limit on nonresonant D production of 4% of the total cross section for D production has been estimated at the 95% confidence level. See C. Simopoulos, Ph.D. Thesis, University of Illinois (1988), unpublished.

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22. The upper limit at 95% confidence level is also included because the likelihood function is asymmetric about the minimum.

Figure Captions

1. Invariant mass plot of $K\pi\pi$ and $K\pi$ combinations. The shoulder in the $K\pi$ invariant mass plot below 1.7 GeV/c^2 is due to the vector pseudoscalar decays of the D^0. The data are fitted to a Gaussian and a polynomial.

2. Mass squared spectra recoiling against a D^+. (a) The curves are the result of a fit to the data. (b) Contributions to the mass squared spectrum recoiling against a D^+. The shape of the curves was determined by Monte Carlo generated data and they are scaled according to the result of the fit.

$$
\begin{array}{llll}
e^+e^- & \to D^{*+}D^{*-} , & D^{*\pm} \to \pi^0 D^\pm & \text{(A)} \\
& \to D^{*+}D^{*-} , & D^{*\pm} \to \gamma D^\pm & \text{(B)} \\
& \to D^{*\pm}D^{\mp} , & D^{*\pm} \to \pi^0 D^\pm & \text{(C)} \\
& \to D^{*\pm}D^{\mp} , & \text{Direct} \quad D^\pm & \text{(D)} \\
& \to D^{*\pm}D^{\mp} , & D^{*\pm} \to \gamma D^\pm & \text{(E)} \\
& \to D^{+}D^{-} , & \text{Direct} \quad D^\pm & \text{(F)}
\end{array}
$$

3. Mass squared spectra recoiling against a D^0. (a) The curves are the result of a fit to the data. (b) Contributions to the mass squared spectrum recoiling against a D^0.

$$
\begin{array}{llll}
e^+e^- & \to D^{*+}D^{*-} , & D^{*\pm} \to \pi^\pm D^0 & \text{(A)} \\
& \to D^{*0}\bar{D}^{*0} , & D^{*0} \to \pi^0 D^0 & \text{(B)} \\
& \to D^{*0}\bar{D}^{*0} , & D^{*0} \to \gamma D^0 & \text{(C)} \\
& \to D^{*\pm}D^{\mp} , & D^{*\pm} \to \pi^\pm D^0 & \text{(D)} \\
& \to D^{*0}\bar{D}^{0} , & D^{*0} \to \pi^0 D^0 & \text{(E)} \\
& \to D^{*0}\bar{D}^{0} , & \text{Direct} \quad D^0 & \text{(F)} \\
& \to D^{*0}\bar{D}^{0} , & D^{*0} \to \gamma D^0 & \text{(G)} \\
& \to D^{0}\bar{D}^{0} , & \text{Direct} \quad D^0 & \text{(H)}
\end{array}
$$

4. Mass squared spectra of wrong sign track combinations.

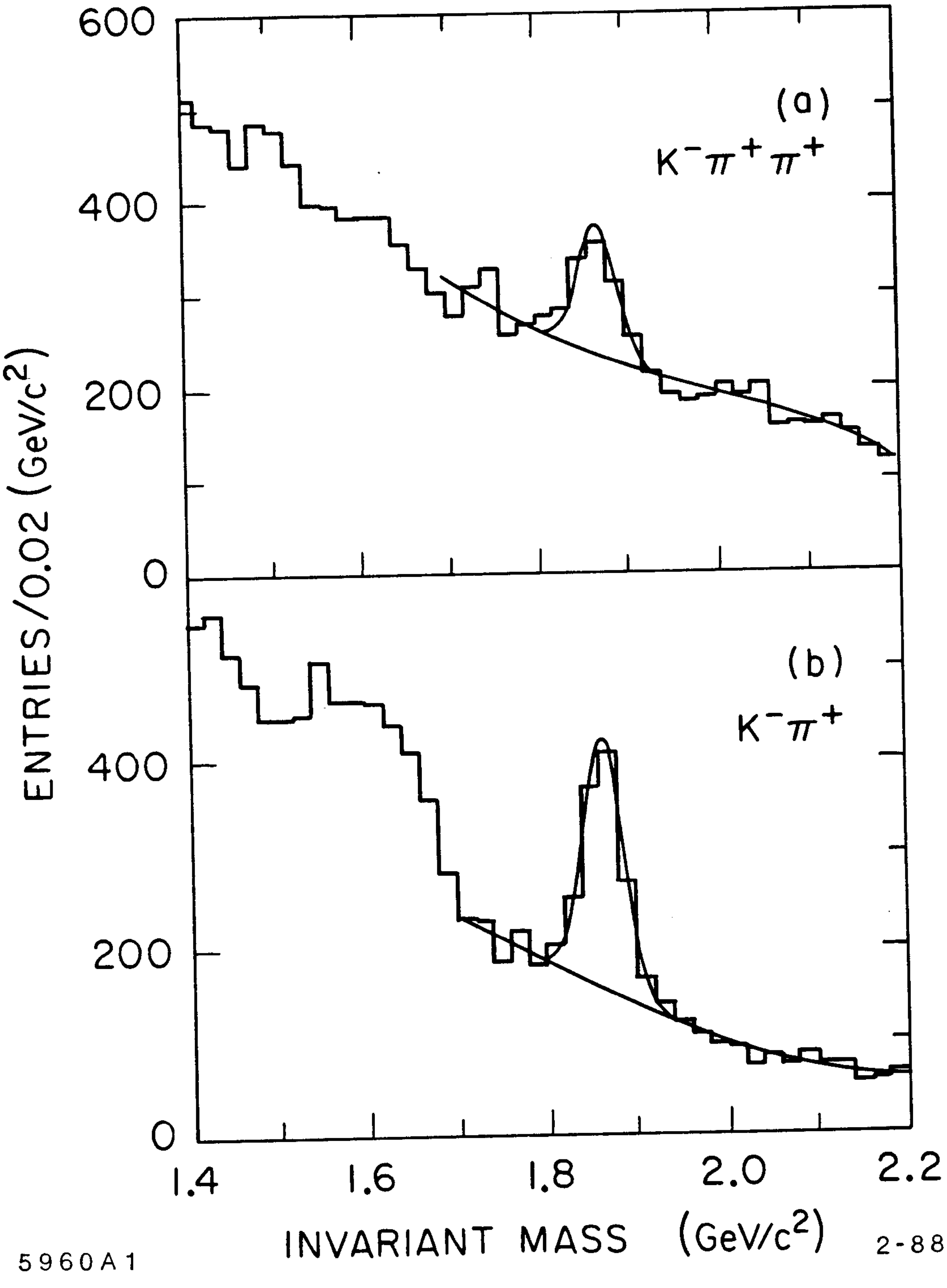
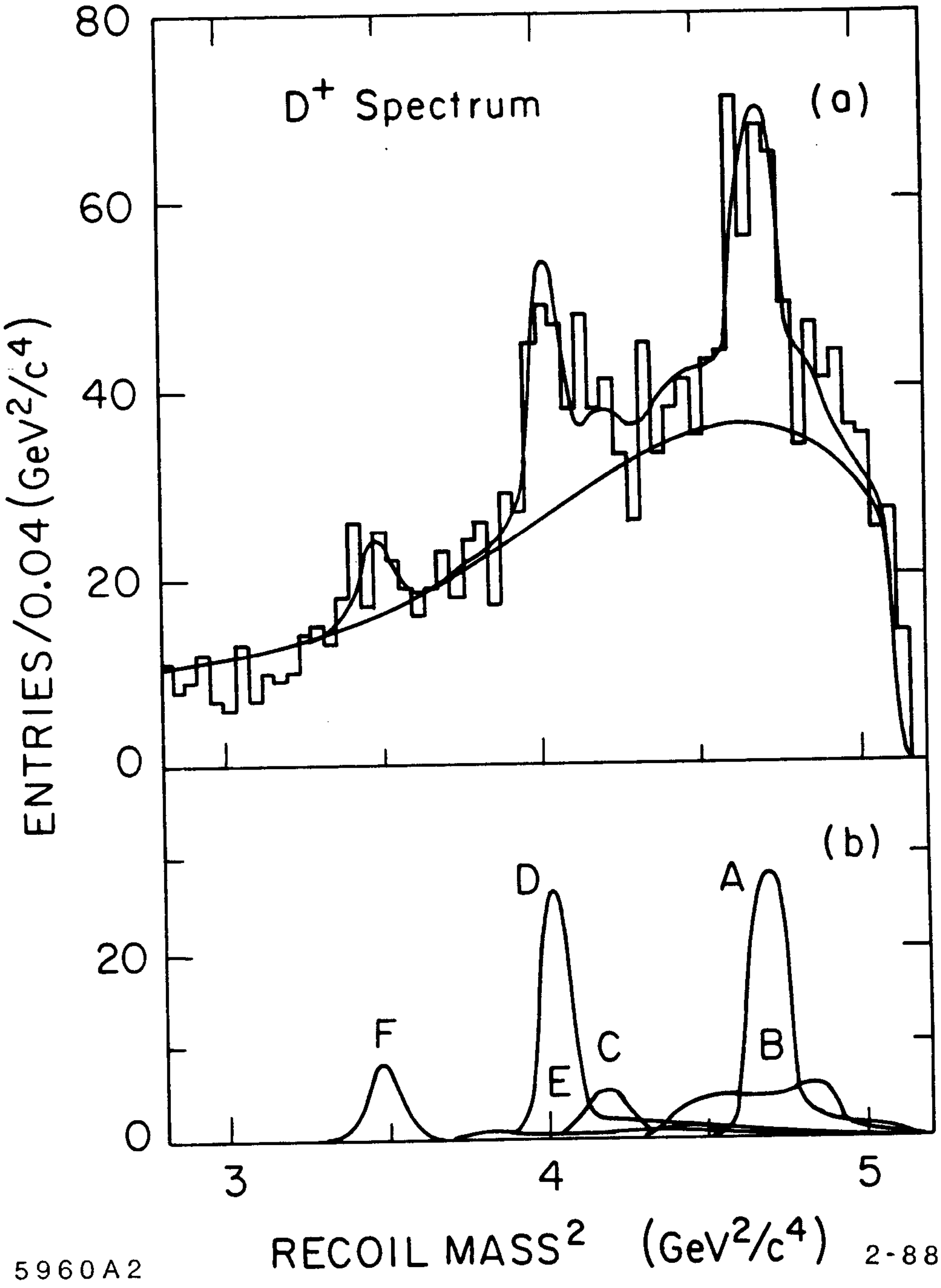
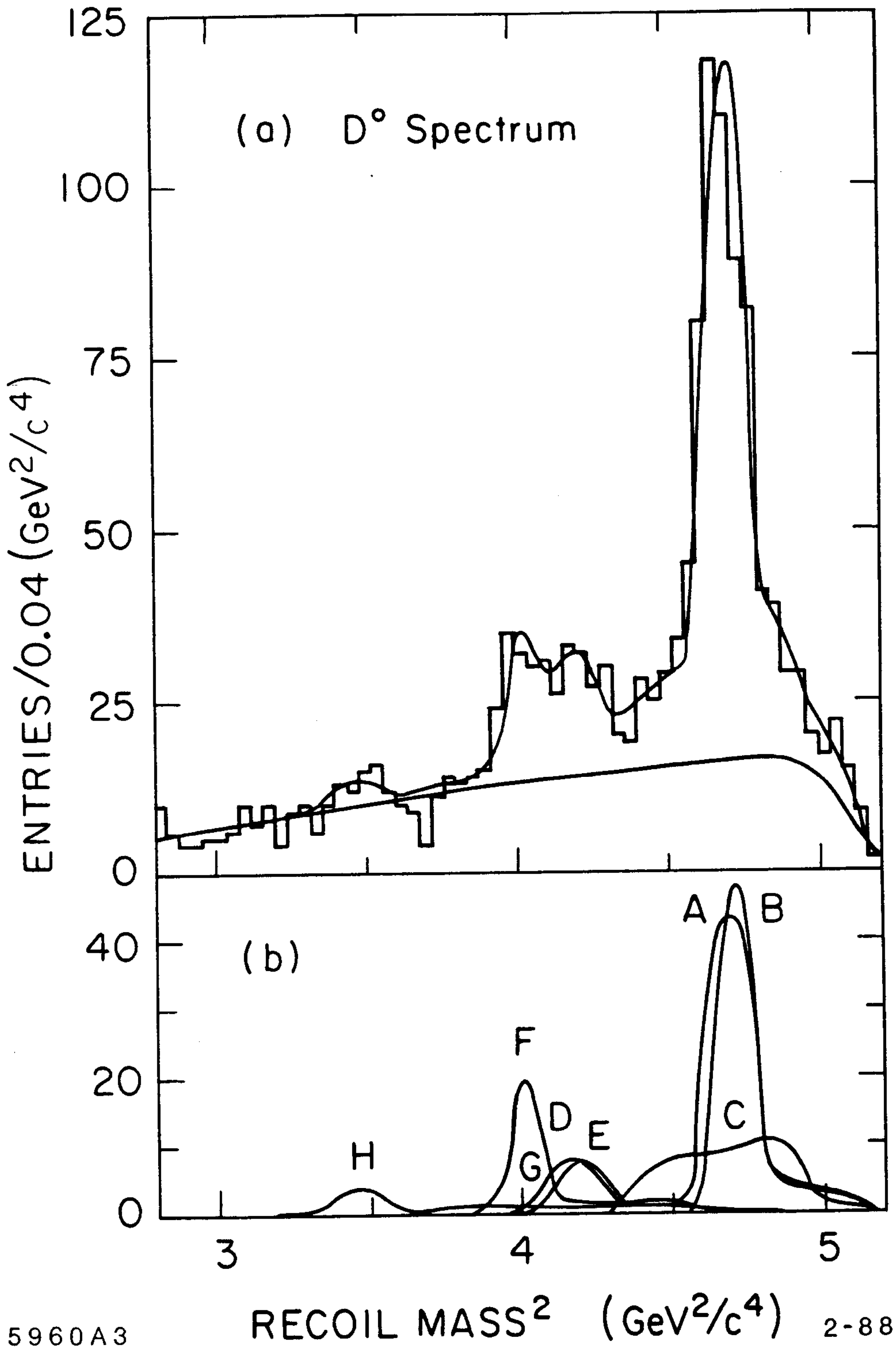

600
400
200
0
400
200
0
ENTRIES/0.02 (GeV/c²)
(a)
K⁻π⁺π⁺
(b)
K⁻π⁺
1.4
1.6
1.8
2.0
2.2
INVARIANT MASS (GeV/c²)
5960A1
2-88

Fig. 1



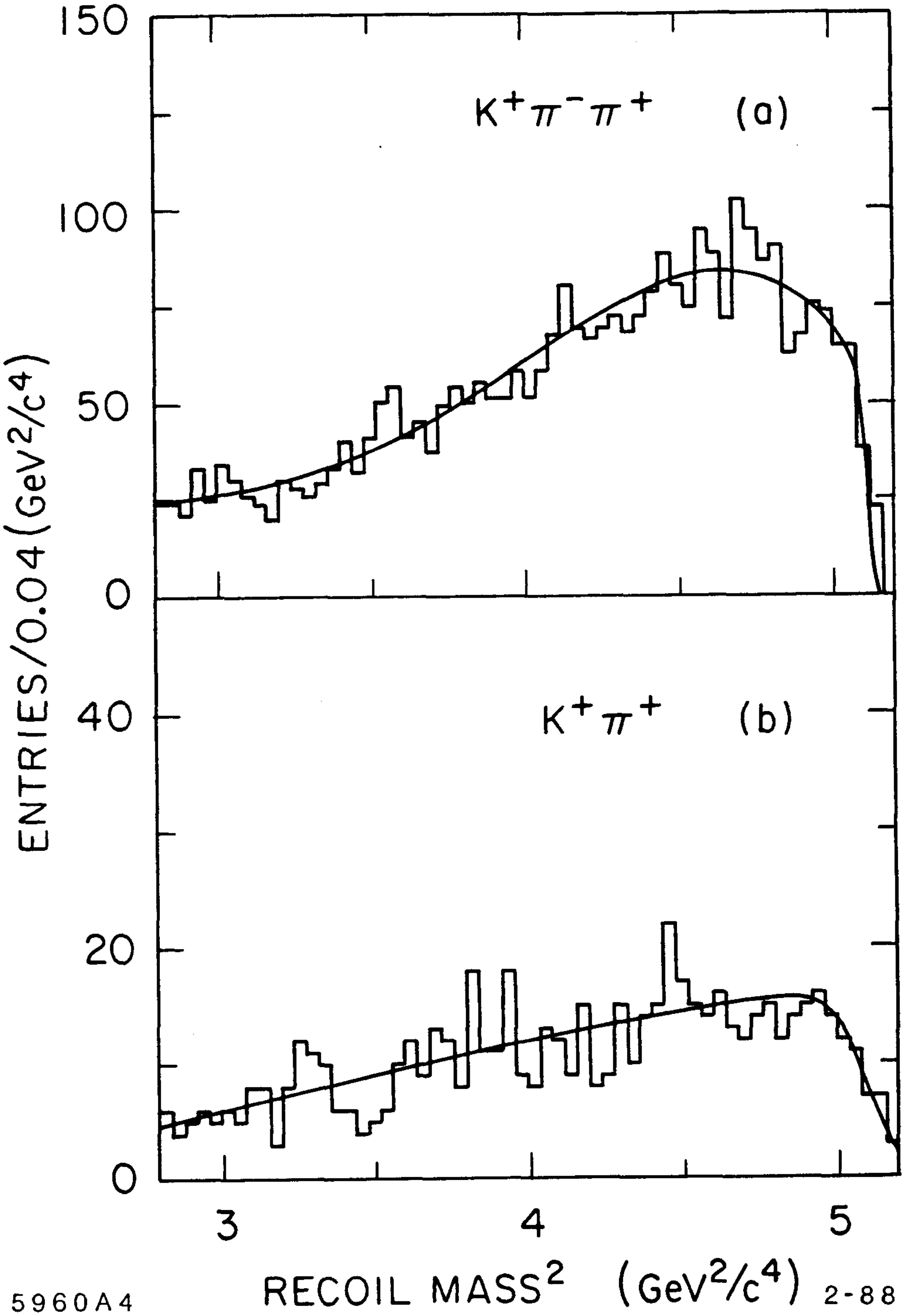
D+ Spectrum
(a)
(b)
80
60
40
20
0
20
0
F
D
E
C
A
B
3
4
5
ENTRIES/0.04 (GeV2/c4)
RECOIL MASS2 (GeV2/c4)
5960A2
2-88

Fig. 2



(a) D° Spectrum
(b)
ENTRIES/0.04 (GeV^2/c^4)
125
100
75
50
25
0
40
20
0
H
F
D
G
E
A
B
C
3
4
5
RECOIL MASS^2 (GeV^2/c^4)
5960A3
2-88

Fig. 3



150
100
50
0
40
20
0
K+ π− π+
(a)
K+ π+
(b)
ENTRIES/0.04 (GeV2/c4)
3
4
5
RECOIL MASS2 (GeV2/c4)
5960A4
2-88

Fig. 4