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OBSERVATION OF CHARMED D MESON PRODUCTION IN pp COLLISIONS

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ABSTRACT

Evidence for the forward production of D^+ mesons has been found in pp collisions at a c.m. energy of 52.5 GeV. A signal of 92 ± 18 events above background has been observed in the decay channel $D^+ \to \overline{K}^{*o}\pi^+ \to K^-\pi^+\pi^+$.

The cross section in the phase space region of our experiment is given and implications for the total cross section for charmed D meson production are discussed.

1. INTRODUCTION

Ever since the prediction of charmed D-mesons [1] and their observation in e^+e^- annihilation [2], considerable experimental effort has been devoted to their detection in hadron-hadron interactions. So far, no direct evidence for charm production in hadron interactions has been found [3]. In an experiment done at higher energy than most prior searches, we have studied the mass distributions of $K^-\pi$ and $K^-\pi\pi$ systems, produced in the forward direction in pp collisions.

2. EXPERIMENT, APPARATUS, TRIGGER

The experiment was performed at the CERN Intersecting Storage Rings (ISR), using the Split Field Magnet (SFM) detector, at a c.m. energy $\sqrt{s}$ = 52.5 GeV. The experimental set-up and procedures of data acquisition and analysis have been described in previous publications [4,5]. The results presented here are based on events obtained by triggering on a negative particle emitted at a c.m.s. polar angle $\theta \sim 8^o$ with a transverse momentum larger than 0.5 GeV/c (see table 1 for a summary of the phase space region covered by the trigger). A threshold Cerenkov counter covering the acceptance of the trigger allowed a separation into "pion" and "non-pion" samples (see [refs 5 and 6] for details). In the non-pion sample, about 80% of the triggering particles are K^-, 20% are $\bar{p}$, and the pion contamination is negligible. In the following presentation, all triggering particles in the non-pion sample are treated as kaons, and all other particles are assumed to be pions.

3. CUTS APPLIED TO THE DATA

The $K^-\pi$ and $K^-\pi\pi$ mass spectra presented below are uncorrected for acceptance and trigger efficiency and subject to some or all of the following selection criteria:

(A) Multiplicity: events are accepted when $n_{obs} \leqslant 10$ (n_{obs} = number of observed particles). This selection reduces the combinatorial background in the $K\pi$ and $K\pi\pi$ spectra.

(B) Leading system in the opposite direction: events are accepted only if $|x_{opp}| > 0.5$ or $|x_{opp}| < 0.1$, where x_{opp} is the total reduced longitudinal momentum seen in the hemisphere opposite to the longitudinal direction of the trigger. This cut selects those events in which a leading system is observed opposite in x to the trigger ($|x_{opp}| > 0.5$) or escapes detection ($|x_{opp}| < 0.1$).

(C) Longitudinal momentum of K^-: the triggering K^- is required to have reduced longitudinal momentum $x_K > 0.3$. This is similar to a P_T cut since the polar angle of the trigger has a small range (see table 1).

(D) Recoiling system in the same longitudinal direction: the "recoiling system" is defined as the set of particles emitted in the same longitudinal direction as the triggering K^-, but with a transverse component opposite to its transverse momentum $\vec{q}_{TK}$. We define a quantity p_R by

$$p_R = - \Sigma k_{Ti} = - \Sigma \vec{p}_i \cdot (\vec{q}_{TK}/|\vec{q}_{TK}|),$$

where the sum is extended over the particles in the recoiling system, i.e. particles with $k_{Ti} < 0$ and $p_{Li} > 0$ (note that $x_K > 0$). Events are accepted only when $p_R > 0.2$ GeV/c. This selection favours events where additional particles are produced close in phase space to the D, which (at least partly) compensate its transverse momentum.

Table 2 contains a summary of the numbers of events fulfilling the various conditions.

4. MASS SPECTRA

The $K^-\pi^+$ mass spectrum is shown in fig. 1. It shows a clear $K^*(890)$ signal, but no evidence for an enhancement in the D^o region. Also in the $K^-\pi^+\pi^+$ mass spectrum no obvious signal corresponding to $D^+ \rightarrow K^-\pi^+\pi^+$ is observed. Since decay of the D via $K^*(890)$ is reported to be an important fraction of its semi-leptonic decay (50 to 70%) [7,8], it is conceivable that the same is also true for the hadronic decay into $K\pi\pi$. Furthermore, the Dalitz plot for the decay $D^+ \rightarrow K^-\pi^+\pi^+$, as observed in e^+e^- annihilation [9], does not exclude the presence of a $\overline{K^{*o}}\pi^+$ contribution.

Therefore, we show in fig. 2 the $K^-\pi^+\pi^+$ mass distribution under the condition that the mass of at least one of the two $(K^-\pi^+)$ pairs is inside the $K^*(890)$ region (of full width 60 MeV around the K^* mass). Indeed, an enhancement is seen in the D mass region, which becomes more pronounced if conditions (C) and (D) are imposed in addition to (A) and (B). Since the quantum numbers of the $\overline{K^{*o}}\pi^+$ system are exotic, the signal is not compatible with any known non-charmed resonance, but it is consistent with the decay $D^+ \rightarrow \overline{K^{*o}}\pi^+$ (i.e. $\Delta C = \Delta S$). We have verified that the signal is not the reflection of a resonance whose decay products have been misidentified.

In order to estimate the significance of the signal and to verify that the signal is not due to kinematics and/or acceptance, three different background spectra have been considered, all obtained from the data with the same selection criteria as used for the $K^-\pi^+\pi^+$ spectrum of fig. 3(a):

(a) the $K^-\pi^-\pi^-$ and $K^-\pi^+\pi^-$ mass distribution (shown in fig. 3(b));

(b) the $K^-\pi^+\pi^+$ distribution obtained by combining the triggering K^- with pions from different events;

(c) the "K^-" $\pi^+\pi^+$ spectrum obtained by assigning the K^- mass to the triggering π^- in the pion sample.

Since none of these background spectra (which all have very similar shapes) show an enhancement in the D-region, we conclude that the signal is genuine and is not generated by the experimental procedure.

The background shown in fig. 3 is obtained by adding the background spectra (a) and (b) mentioned above and normalizing to the number of $K\pi\pi$ combinations outside the D-region (i.e. the three bins from 1.8 to 2.04 GeV, in which the signal is seen). Subtraction of this background yields a signal of

$$92 \pm 18 \text{ events}.$$

We have estimated the mass of the D to be $M = 1.91$ GeV/C^2. The difference of 40 MeV/C^2 between our estimation and published results is compatible with local systematic errors added to the statistical uncertainty $\sigma = 20$ MeV/C^2. The width of the signal is compatible with our experimental mass resolution (FWHM = 150 MeV/C^2).

5. CORRECTIONS AND CROSS SECTIONS

The inclusive cross section for D production has been determined by Monte-Carlo methods, taking account of the experimental acceptance and the cuts on kaon momentum and $K^-\pi^+$ mass. Generating a sample of K^- events into the same acceptance region as for the D, we obtain the absolute normalization by comparison with published K^- data [10] (after correction for the $\bar{p}$ content of the trigger sample).

The losses in signal due to the cuts on event topology ((A), (B) and (D) in sect. 3) have been estimated by inspection of the complementary sample of rejected events; by the absence of a D signal in this sample we obtain an additional contribution which is at most 28 events.

The acceptance region of our trigger for D mesons (Ω_D) covers a sizeable fraction of phase space ($\phi \in (90, 270)$, $y \in (1.7, 3.2)$ and full p_T range), considerably larger than the corresponding region for the K^- trigger particle. Consequently our global acceptance for D mesons in Ω_D, and the resulting estimation of the cross-section $(B.\sigma)_{\Omega_D}$, are sensitive to the momentum dependence of D production. We have therefore performed model calculations with various assumptions about the longitudinal and transverse momentum dependence of the D cross section.

We assume scaling and approximate factorization in the form

$$E\,\frac{d^3\sigma}{d^3p} \sim f(y/y_{max})\;e^{-Ap_T}\;,$$

where y_{max} (p_T) is the maximum rapidity allowed by kinematics.

Two different p_T slope parameters, A = 2 and A = 2.8 (GeV/c)$^{-1}$ are chosen. The function $f(y/y_{max})$ is adjusted to generate three different production mechanisms: proportional to $(1 - x)^3$, uniform in rapidity and uniform in x. Isotropic decay angle distributions are assumed for both the decays $D^+ \to K^{*o}\pi^+$ and $K^{*o} \to K^-\pi^+$. The corresponding inclusive cross sections in our acceptance region Ω_D, $(B\cdot\sigma)_{\Omega_D}$, are presented in table 3. They are rather sensitive to the slope parameter A and can vary by a factor of 6 under extreme assumptions.

Table 3 also gives estimates of the corresponding total cross section $(\sigma \cdot B)_{tot}$, where further uncertainties are introduced due to the extrapolation to the full rapidity range. In this case, the values change by up to a factor of 15 for the different production mechanisms. Apart from these uncertainties, the individual values for the different models have an estimated error of $\sim$ 40%, due to the following contributions:

- Uncertainty in the size of the signal (including the correction for the cuts on event topology): $\sim$ 30%;
- Uncertainty in the acceptance calculation: $\sim$ 20%;
- Uncertainty in the absolute normalisation: $\sim$ 30%.

If we assume [8] that $\sim$ 2/3 of the measured decay $D^+ \to K^-\pi^+\pi^+$ [11] proceeds via K^{*o} formation, we obtain a branching ratio of (2.6 ± 1.0)% for our decay channel. This would correspond to a total cross section for D^+ production between 150 and 2000 μb (with errors of $\sim$ 60%), depending on the production mechanism. The higher value is incompatible with measured upper limits for D production at ISR energies [12]; hence our data indicate that the D is produced with a rather flat distribution in p_T and rapidity or Feynman x. This mechanism would also help in understanding the results of the CERN beam dump experiments [13].

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TABLE CAPTIONS

Table 1 Parameters characterizing the kinematical region covered by the acceptance of the K^- trigger.

Table 2 Number of events fulfilling the various conditions imposed on the data sample.

Table 3 Summary of cross sections for D production obtained by different model calculations.

Table 1

Variable	Range	Mean	FWHM	r.m.s.
x	0.2 - 0.6	0.31	0.09	0.04
y	2 - 3	2.65	0.38	0.15
p_T (GeV/c)	> 0.5	1.15	0.55	0.27
θ	$5^{\circ} - 13^{\circ}$	8.0°	3.1°	1.28°
ϕ	$144^{\circ} - 168^{\circ}$	158°	10.4°	3.9°
	$174^{\circ} - 216^{\circ}$	193°	21.2°	7.4°

Table 2

Condition	Nb. of events fulfilling condition before K^* selection	Nb. of events fulfilling condition after K^* selection
none	98 884	8910
(C)	49 707	4055
(A) (B)	37 376	3457
(A) (B) (C)	18 561	1580
(A) (B) (C) (D)	12 124	977

Table 3

Longitudinal dependence	p_T slope A, $(GeV/c)^{-1}$	$(B\cdot\sigma)_{\Omega_D}$ μb	$(B\cdot\sigma)_{tot}$ μb
$d\sigma/dx \propto (1-x)^3$	2 2.8	2.81 8.40	21.6 62.0
$d\sigma/dy$ = const	2 2.8	1.67 4.38	7.5 19.3
$d\sigma/dx$ = const	2 2.8	1.44 3.80	4.0 10.5

FIGURE CAPTIONS

Fig. 1 The $K^-\pi^+$ mass distribution obtained without cuts (full line) and with conditions (A), (B) (broken line).

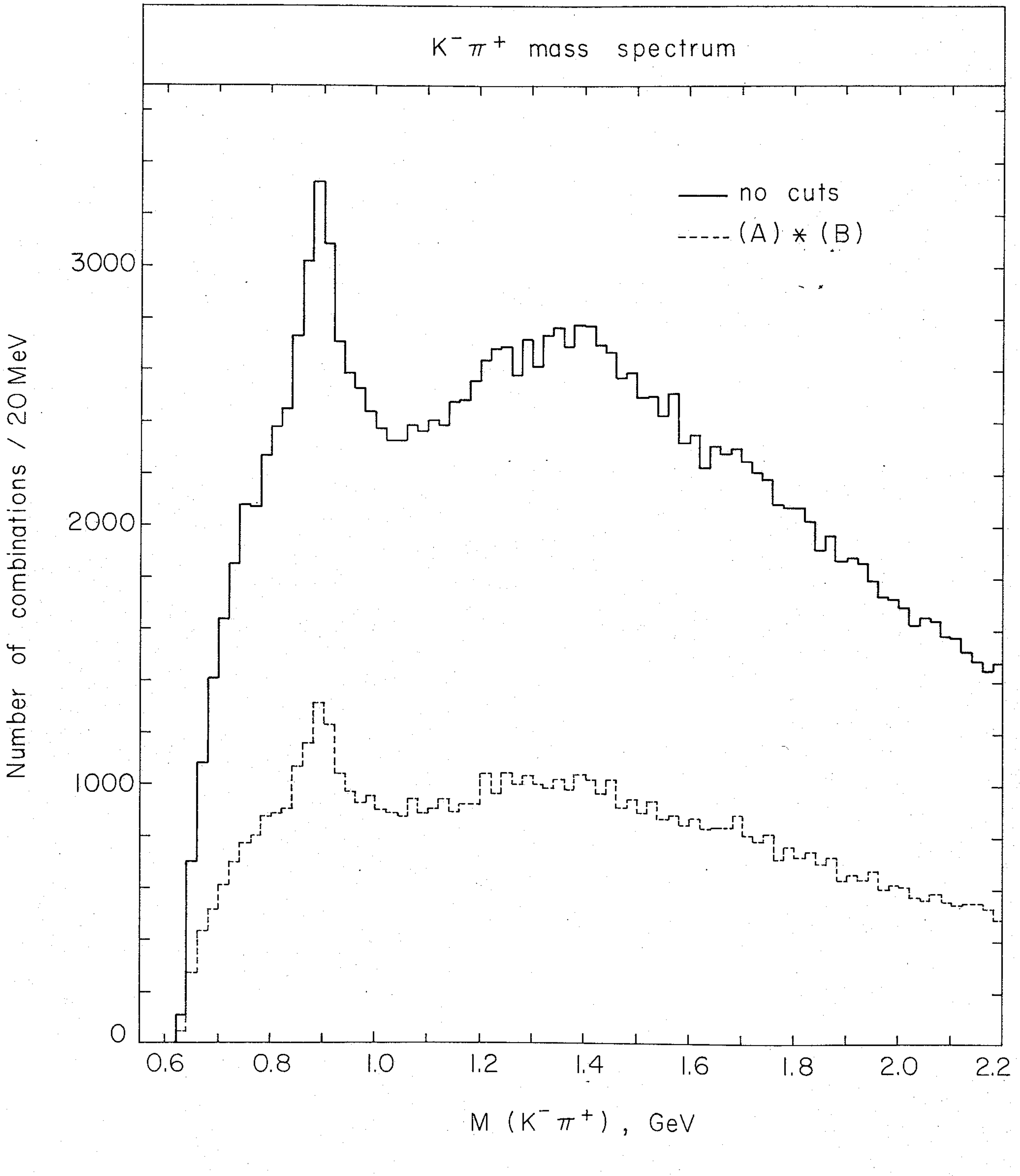
Fig. 2 The $K^-\pi^+\pi^+$ mass distribution under the condition that at least one of the two $K^-\pi^+$ combination has a mass in the K^* region (± 30 MeV around the K^* mass), for events fulfilling various conditions: (A) and (B) (full line), (A), (B) and (C) (broken line), and (A), (B), (C) and (D) (shaded histogram).

Fig. 3 $K^-\pi\pi$ mass distributions under the condition that at least one of the two $K^-\pi$ combinations (independent of their charge) has a mass in the K^* region, for events fulfilling conditions (A), (B), (C) and (D):

(a) $K^-\pi^+\pi^+$,

(b) Sum of $K^-\pi^+\pi^-$ and $K^-\pi^-\pi^-$.

The broken line represents the background obtained by the procedure outlined in sect. 4.



K⁻π⁺ mass spectrum
no cuts
(A) * (B)
Number of combinations / 20 MeV
3000
2000
1000
0
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
M (K⁻π⁺) , GeV

Fig. 1

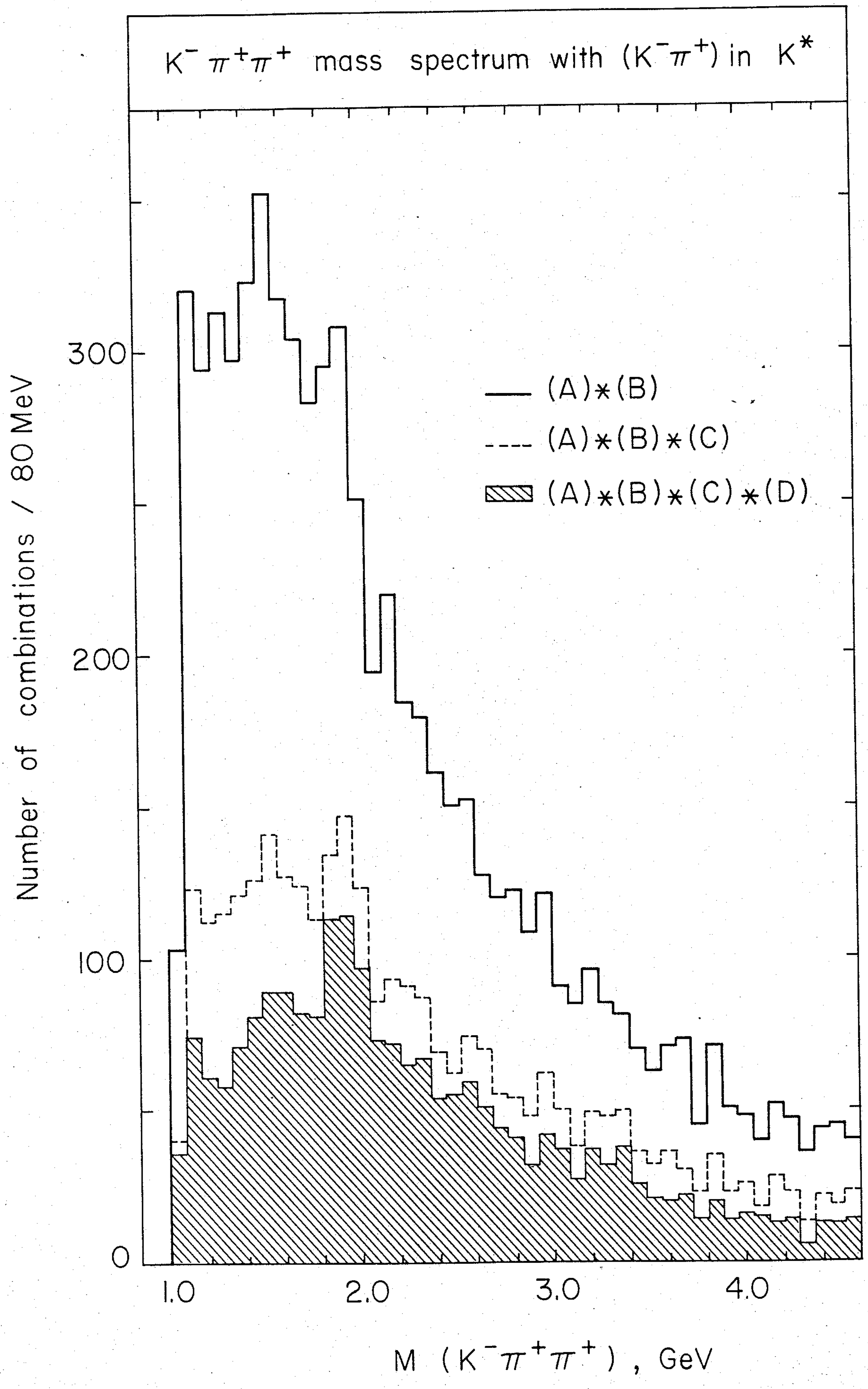
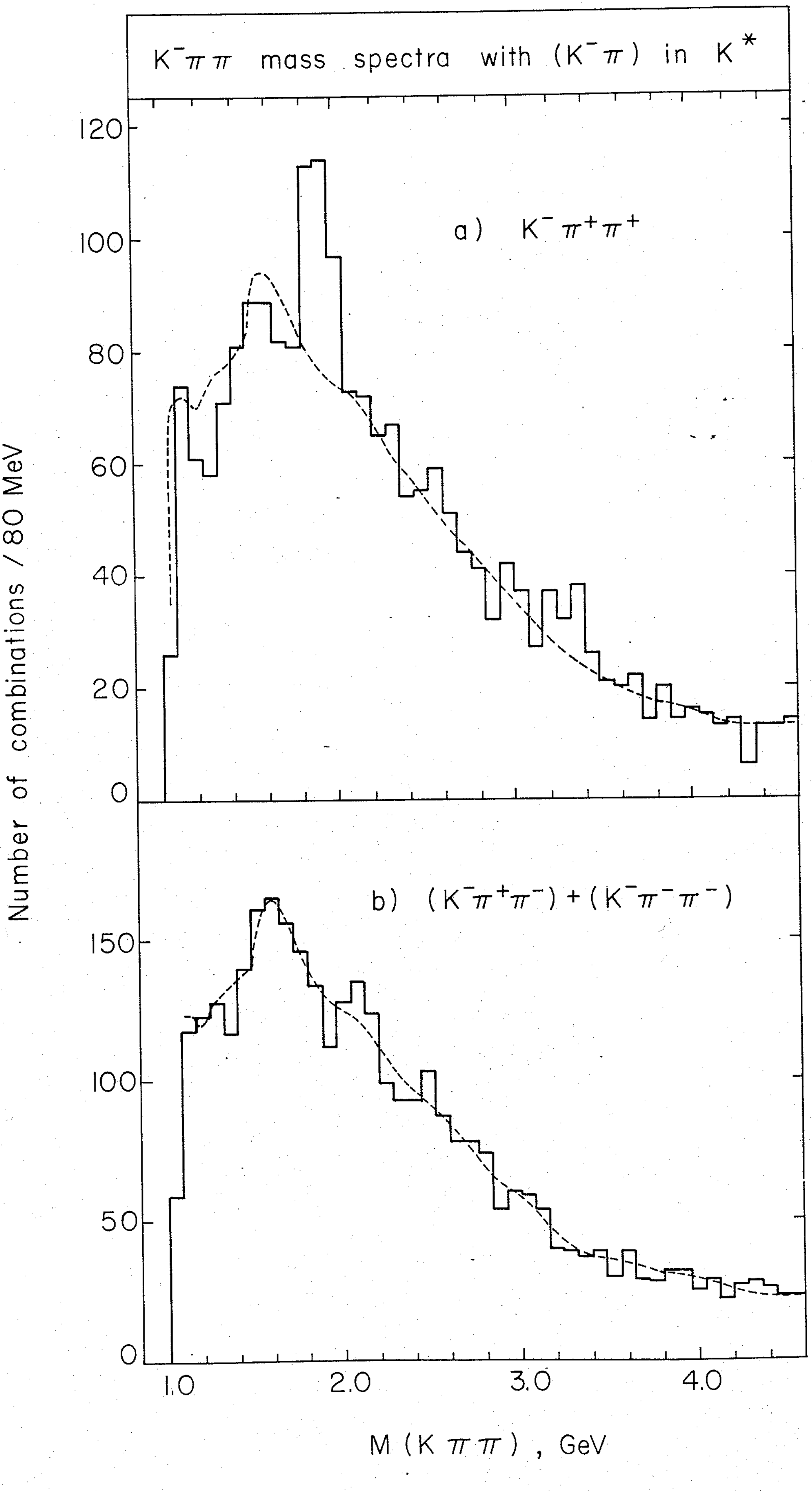

K⁻ π⁺π⁺ mass spectrum with (K⁻π⁺) in K*
(A)*(B)
(A)*(B)*(C)
(A)*(B)*(C)*(D)
Number of combinations / 80 MeV
0
100
200
300
1.0
2.0
3.0
4.0
M (K⁻π⁺π⁺) , GeV

Fig. 2



K⁻ππ mass spectra with (K⁻π) in K*
a) K⁻π⁺π⁺
b) (K⁻π⁺π⁻)+(K⁻π⁻π⁻)
Number of combinations / 80 MeV
120
100
80
60
40
20
0
150
100
50
0
1.0
2.0
3.0
4.0
M (Kππ) , GeV

Fig. 3