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BACKWARD PRODUCTION OF A SPIN-PARITY 1^+ Kρ RESONANCE AT 1.28 GeV

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ABSTRACT

A $(K\pi\pi)^+$ mass enhancement is observed in the reactions $K^-p \to \Xi^- K^0 \pi^+ \pi^0$ when events with a small $(K^- \to \Xi^-)$ four momentum transfer squared are selected. The signal is also visible in the reaction $K^-p \to \Xi^-\pi^+$ + neutrals. The enhancement, centered at 1.28 GeV, is seen to decay preferentially into Kρ with spin-parity $J^P = 1^+$. The cross section for $K^-p \to \Xi^-C^+(1.28)$ with $C^+ \to K\rho$ at 4.15 GeV/c incident K^- momentum is $(6.2 \pm 0.6)\mu b$.

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The non-relativistic quark model predicts within the lowest radial excitation the existence of two nonets of mesons with $J^{PC} = 1^{+\pm}$. The first evidence for an axial vector $K\pi\pi$ resonance, called the C-meson, was observed in $\bar{p}p$ annihilations at rest [1]. Later, further evidence came from the study of diffraction-like processes [2]. The "Q" $K\pi\pi$ diffractive enhancement is currently interpreted in terms of two resonances, Q_1 and Q_2, superimposed on a large background [3]. The first state, Q_1, has a mass around 1300 MeV, a width of 150 MeV albeit with large errors and decays mainly into $K\rho$. The second state, Q_2, has a mass around 1400 MeV, a width of about 150 MeV, and decays mainly into $K^*\pi$. What is perhaps more relevant to the results presented in this letter, the Q has also been observed to be produced in the backward direction of K^+p interactions [4], the production mechanism being presumably dominated by Λ exchange.

In a systematic search for backward produced resonances in K^-p interactions, we have recently observed backward production of the $J^{PC} = 1^{++}$ A_1 meson [5] as well as backward production of the $J^{PC} = 1^{+-}$ B meson [6]. Taking advantage of the large statistics available (approximately 133 events per microbarn), we have also investigated the properties of the reactions

$$K^-p \rightarrow \Xi^-(K\pi\pi)^+ \qquad (1)$$

where the Ξ^- is produced with small $|u|$ (u is the K^- to Ξ^- four-momentum transfer squared).

The data come from a series of exposures of the CERN 2m hydrogen bubble chamber to K^- beams of momenta in the range 4.09 to 4.25 GeV/c, in which a total of 3.1 million pictures were taken.

Four reactions have been analysed

$K^-p \rightarrow \Xi^-K^+\pi^+\pi^-$	1971 events	(1a)
$K^-p \rightarrow \Xi^-K_1^o\pi^+\pi^o$	759 events	(1b)
$K^-p \rightarrow \Xi_1^-\pi^+$ + neutrals	1716 events	(1c)
$K^-p \rightarrow \Xi_1^-K^+$ + neutrals	1039 events,	(1d)

the number of events are those obtained after various selections have been applied (see below). The subscript 1 indicates that the subsequent vee, K^o or Λ, was required for event identification. Since, no kinematic constraint is available at the production vertex for reactions (1c) and (1d), we consider them more as a check for the results we shall present on the kinematically constrained reactions (1a) and (1b), than as a direct evidence for the presence of $(K\pi\pi)$ resonances. In addition to the kinematic fit selection, we introduce cuts on the useful fiducial volume impose that the projected length of the Ξ^- is larger than 5 mm and that its projected decay angle is larger than 60 mrad. We then correct for these cuts by a subsequent weighting of the events. The average weights for reaction (1a) and (1b) amount to 1.27 and 1.44 respectively, not taking into account the unseen decay modes of the K^o and Λ's.

Although reaction (1b) contains an unseen π^o, the observation of a K^o decay allows a rather clean selection of these events. Moreover, the $\Xi\pi$ and $\Xi\pi\pi$ mass distributions indicate that the background coming from the Ξ^* channels is less severe for reaction (1b) than for (1a).

Fig. 1 shows the $(K\pi\pi)^+$ mass spectra for $|u| < 1.5$ GeV^2. Note that, for reactions (1c) and (1d), the (π^+MM) and (K^+MM) effective masses include also many-body systems, i.e. $(K3\pi)$'s which cannot be separated. An enhancement is visible at about 1.28 GeV in the three spectra corresponding to reactions (1a-c) and in their sum. We shall see later that the absence of this enhancement in reaction (1d) is to be expected. No clear evidence for a second enhancement at 1.40 GeV is visible in the mass spectra. The expected contribution of the $J^P = 2^+K^*(1420)$ is 5 ± 5 events since it is not seen in the reaction

$$K^-p \to \Xi^-K^o\pi^+ \qquad (2)$$

where its two-body decay mode could have been observed.

We have checked that the enhancement observed in the $(K\pi\pi)$ mass spectra is not due to the reflection of the Ξ^*'s which remain after the u selection has been applied.

Since the signal to background ratio is the largest for reaction (1b), we show in fig. 2(a) the Chew-Low plot for the $K\pi\pi$ system produced in this reaction. One sees a distinct accumulation of events at small $|u|$ around 1.28 GeV but no clear accumulation around 1.40 GeV. The cut at $|u| < 1.5$ GeV^2 preserves most of the ($K\pi\pi$) accumulation and eliminates a large fraction of the background. This cut will be systematically applied in the following analysis.

Fig. 2(b-d) show the mass scatter plots of the $K^o\pi^+\pi^o$ system for reaction (1b). The $\pi^+\pi^o$ vs $K^o\pi^+\pi^o$ scatter plot shows a concentration of events in the ρ mass region for $M(K^o\pi^+\pi^o) \sim 1.28$ GeV. The two $K\pi$'s vs $K^o\pi^+\pi^o$ scatter plots show that the density of events is not enhanced when the K^* mass band crosses the $K\pi\pi$ enhancement. From these qualitative considerations it seems that the 1.28 GeV $K\pi\pi$ enhancement is mainly associated with $K\rho$. This particular decay mode explains why it is not seen in reaction (1d), since a ($K^+\rho$) system cannot produce the ($K^+\pi^o\pi^o$) final state.

These conclusions are reinforced by a quantitative multi-channel likelihood analysis of reactions (1a) and (1b) [7]. In this analysis the $K^*(890)$ and $\rho(770)$ masses and widths are fixed at 892 MeV, 50 MeV, 776 MeV and 155 MeV respectively. The masses and widths of the $\Xi^*(1530)$ and $\Xi^*(1820)$ are fixed at 1532 MeV, 12 MeV and 1821 MeV, 16 MeV respectively. The $K\pi\pi$ enhancement observed at 1280 MeV, called C(1280), is represented by a S-wave Breit-Wigner function with M = 1275 MeV, Γ = 75 MeV, these values being obtained from the fit described later. To evaluate quantitatively the hypothetical presence of a second $K\pi\pi$ resonance in our data, called C'(1400), we also introduce in the fit a $K\pi\pi$ S-wave Breit-Wigner with M = 1400 MeV and Γ = 120 to 200 MeV.

The fractions attributed to the various channels which contribute to reactions (1c) and (1b) are given in the table. For both reactions, the three-body channel $\Xi^-K\rho$ is negligible whereas $\Xi^-K^*\pi$ represents a significant fraction of the sample. Even after the $|u|$ cut has been applied, the contribution of the $\Xi^*(1530)$ channels is important, in particular for the quasi two-body process $\Xi^*(1530)$ $K^*(890)$ which reflects in the 1400 MeV $K\pi\pi$ mass region. No significant contribution from the C'(1400) is observed, whereas the C(1280), and in particular the C(1280) $\rightarrow K\rho$ decay mode, represents a large fraction of reactions (1a) and (1b). Summing up the observed contributions from reaction (1a) and (1b), we find that 363 ± 35 events should be attributed to C(1280) $\rightarrow K\rho$ and 95 ± 31 to C(1280) $\rightarrow K^*\pi$.

From these results, and assuming no interference between the two decay amplitudes, one obtains a branching ratio

$$\frac{C(1280) \rightarrow K\rho}{C(1280) \rightarrow (K^*\pi + K\rho)} = 0.8 \pm 0.1,$$

if the isospin of C(1280) is $I = \frac{1}{2}$. This result deviates by nearly three standard deviations from the value of 0.5 predicted by pure SU(3). Note that this SU(3) ratio reduces to 0.4 if phase space is taken into account.

The interpretation of this 1.28 GeV $K\pi\pi$ enhancement as a resonance would require a full partial wave analysis, a very difficult task with the available statistics. In the following we investigate the possibility of a resonance interpretation with a simplified partial wave analysis. This analysis involves maximum likelihood fits on the Dalitz plots for different $K\pi\pi$ mass regions [8]. For each spin-parity assignment the absolute square of the amplitude is assumed to be an incoherent sum of terms describing the $K\pi\pi$ states and a constant describing the background. The $K\pi\pi$ amplitudes are constructed using the Zemach representation [9] for the following spin-parity assignments:

- $K\rho$ and $K^*\pi$ amplitudes, $J^P = 0^-, 1^+S, 1^+D, 1^-, 2^-P, 2^+$.

Interference terms have been introduced between $K\rho$ and $K^*\pi$ amplitudes with the same spin-parity assignments. On the other hand, no attempt has been made to introduce $K\varepsilon$ or $\kappa\pi$ amplitudes. Note that ε is in any case forbidden for reaction (1b). We have assumed $I = \frac{1}{2}$ for the $K\pi\pi$ system and have introduced a cut at $|u| < 1.5$ GeV^2. As discussed previously, this cut is not sufficient to eliminate the important production of $\Xi^*(1530)$. We have therefore rejected the events with $1.52 < M(\Xi^-\pi^+) < 1.55$ GeV from this spin-parity analysis. Relaxing this cut does not in fact change our conclusions on the spin-parity of the $K\pi\pi$ enhancement.

All the fits tried independently for reactions (1a) and (1b) gave remarkably similar results for the 1.28 GeV $K\pi\pi$ enhancement. The events assigned to the $J^P = 1^+$ $K\rho$ S-wave amplitude appear to give the most important contribution to the enhancement observed at 1.28 GeV. A small $K^*\pi$ amplitude appears to be centered at 1.28 GeV and corresponds to $J^P = 1^+$ $K^*\pi$ S-wave. Fig. 3 shows the results of the partial wave analysis for the terms which give a significant contribution of the fit, i.e. 1^+ $K\rho$ S-wave, $1^+K^*\pi$ S-wave and "background". The present statistics do not allow to draw any conclusion about a $1^+K^*\pi$ resonance around 1400 MeV.

We are led to the conclusion that we observe in reaction (1a) and (1b), the production of a $J^P = 1^+$ resonance decaying mainly into $K\rho$ and centered at 1.28 GeV. A relativistic S-wave Breit-Wigner function has been fitted to this $K\rho$ enhancement using a polynomial of fourth order for the background. To take into account threshold effects in the $K\pi\pi$ mass spectrum, we used the simple parametrization proposed in [3a]. The results are (fig. 1)

$$M = 1275 \pm 10 \text{ MeV} \qquad \Gamma = 75 \pm 15 \text{ MeV}.$$

These results, together with the $K\rho$ dominant decay mode, are in fair agreement with the previous observations of the C-meson in $\bar{p}p$ annihilations [1,10] although our mass value is higher. The dominant $K\rho$ decay mode is also in agreement with the results obtained with K diffractive processes [2,3]. It is however more difficult to compare our results for the mass and width to those obtained in diffractive processes in view of the large uncertainties which affect the last ones.

The $K\rho$ decay mode of the C(1280) being well established, we have looked for a possible $K\omega$ decay mode studying the reaction

$$K^-p \to \Xi^-K^+\pi^+\pi^-\pi^o, \qquad (3)$$

from the same experiment. Reaction (3) shows a clear $\omega^o \to \pi^+\pi^-\pi^o$ peak (not shown) but, selecting the ω^o with a mass cut $0.75 < M(\pi^+\pi^-\pi^o) < 0.83$ GeV and introducing the u cut used in the $K\rho/K^*\pi$ analysis, i.e. $|u| < 1.5$ GeV^2, we find no significant evidence for a $K\omega$ enhancement with the mass and width assigned to the C(1280) (see insert in fig. 1). Taking the shaded area of this mass distribution above the curve corresponding to phase-space, we quote the following upper limit for the $C^+(1280) \to K^+\omega^o$ cross section (including corrections for the neutral decay mode of the ω^o)

$$\sigma(C^+(1280) \to K^+\omega^o) \leqslant 0.3\ \mu b.$$

This limit gives an upper limit of 0.05 for the branching ratio $C(1280) \to K\omega / C(1280) \to K\rho$.

The cross sections for reactions (1a) and (1b) are found to be 23 ± 2 μb and 29 ± 3 μb, respectively, all corrections for scanning losses and unseen decay modes being included. Using the results given in the table, and assuming $I = \frac{1}{2}$ for $C^+(1280)$ and $C'^+(1400)$ we get the cross sections for $|u| < 1.5$ GeV^2

$\sigma(C^+(1280) \to K\rho)$	6.2 ± 0.6 μb
$\sigma(C^+(1280) \to K^*\pi)$	1.7 ± 0.5 μb
$\sigma(C'^+(1400) \to K\rho)$	< 0.2 μb
$\sigma(C'^+(1400) \to K^*\pi)$	< 0.5 μb.

The cross section obtained here for C(1280) is close to the one for A_1 production in a similar process

$$K^- p \to \Sigma^- A_1^+(1040),$$

which corresponds to (7.2 ± 1.0)μb for $A_1^+ \to (\rho\pi)^+$ [5]. The slope of the differential cross section $d\sigma/du \sim \exp(-b|u|)$, with $b = 1.60 \pm 0.30$ GeV^{-2} for $C^+(1280)$ is of the same order as the one observed for the A_1 ($b = 2.15 \pm 0.35$ GeV^{-2}) [5].

The properties of the $C^+(1280)$ production are characteristic of "Λ" or "Σ" exchange in the u-channel. If it were pure "Σ" exchange, one should expect to observe 363 $C^0(1280)$ events corresponding to the reaction

$$K^-p \rightarrow \Xi^0 C^0, \; C^0 \rightarrow K^0 \rho^0.$$

This number can be compared to the upper limit of $\sim$ 50 events actually observed in this experiment, this suggesting a dominant Λ exchange process similar to that for the backward production of the $A_1(1040)$ [5]. This result is compatible with the observation by Firestone [4] of backward produced Q in K^+p interactions which also favours the exchange of a Λ^0.

We conclude that we have observed evidence for a resonance in the $K\pi\pi$ mass spectrum coupled to neutral baryon exchange. Its properties are in agreement with the previous observation of the C-meson in $\bar{p}p$ annihilation at rest, and with the observation of the Q_1 meson in diffraction-like processes. We find no evidence for a 1^+ S-wave $K^*\pi$ resonance in the mass range near 1400 MeV. One possible explanation could be that different production mechanisms are at work for Q_1 and Q_2 [11].

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TABLE CAPTION

Table 1 Channel decomposition of the reactions $K^- p \to \Xi^- K^o \pi^+ \pi^o$ and $K^- p \to \Xi^- K^+ \pi^+ \pi^-$. The number of events given in this table are weighted to take into account the selections described in the text and include the cut: $|u| < 1.5$ GeV^2.

Table 1

Channel	Fraction %	Number of events
	$K^- p \to \Xi^- K^o \pi^+ \pi^o$	
$\Xi^- K^o \rho^+$	.00 ± .04	1 ± 23
$\Xi^- K^{*+}_{890} \pi^o$	.15 ± .04	86 ± 23
$\Xi^- K^{*o}_{890} \pi^+$	.01 ± .03	4 ± 17
$\Xi^{*o}_{1530} K^o \pi^o$	.02 ± .02	13 ± 10
$\Xi^{*-}_{1530} K^o \pi^+$	.07 ± .02	40 ± 15
$\Xi^{*o}_{1530} K^{*o}_{890}$	.05 ± .02	29 ± 10
$\Xi^{*-}_{1530} K^{*+}_{890}$	.08 ± .02	46 ± 14
$\Xi^{*o}_{1820} K^o$	.01 ± .01	7 ± 6
$\Xi^- C^+_{1280} \to (K^* \pi)^+$	.06 ± .03	35 ± 18
$\Xi^- C^+_{1280} \to (K \rho)^+$	.28 ± .04	162 ± 23
$\Xi^- C'^+_{1400} \to (K^* \pi)^+$	.02 ± .02	11 ± 15
$\Xi^- C'^+_{1400} \to (K \rho)^+$	.00 ± .03	0 ± 21
Phase space	.25 ± .05	151 ± 33
	$K^- p \to \Xi^- K^+ \pi^+ \pi^-$	
$\Xi^- K^+ \rho^o$	.00 ± .03	3 ± 36
$\Xi^- K^{*o}_{890} \pi^+$	.13 ± .03	167 ± 40
$\Xi^{*o}_{1530} K^+ \pi^-$	.14 ± .02	183 ± 26
$\Xi^{*o}_{1530} K^{*o}_{890}$	.13 ± .02	165 ± 24
$\Xi^{*-}_{1820} K^+$	.06 ± .01	74 ± 13
$\Xi^- C^+_{1280} \to (K^* \pi)^+$	.05 ± .02	60 ± 26
$\Xi^- C^+_{1280} \to (K \rho)^+$	.15 ± .02	201 ± 28
$\Xi^- C'^+_{1400} \to (K^* \pi)^+$	.02 ± .02	26 ± 24
$\Xi^- C'^+_{1400} \to (K \rho)^+$	.01 ± .02	17 ± 24
Phase space	.31 ± .03	410 ± 42

FIGURE CAPTIONS

Fig. 1 $(K\pi\pi)^+$ effective mass spectra for the reactions:

(a) $K^-p \rightarrow \Xi^-K^+\pi^+\pi^-$,

(b) $K^-p \rightarrow \Xi^-K^o\pi^+\pi^o$,

(c) $K^-p \rightarrow \Xi^-\pi^+$ + neutrals,

(d) $K^-p \rightarrow \Xi^-K^+$ + neutrals,

and for the sum of (a), (b) and (c). Weighted events have been used and a u-cut has been applied: $|u| < 1.5$ GeV^2. The curve corresponds to the fit described in the text. The insert shows the $K^+\omega^o$ mass spectrum for the reaction $K^-p \rightarrow \Xi^-K^+\pi^+\pi^-\pi^o$ with the ω^o selection described in the text.

Fig. 2 $K^-p \rightarrow \Xi^-K^o\pi^+\pi^o$ scatter plots:

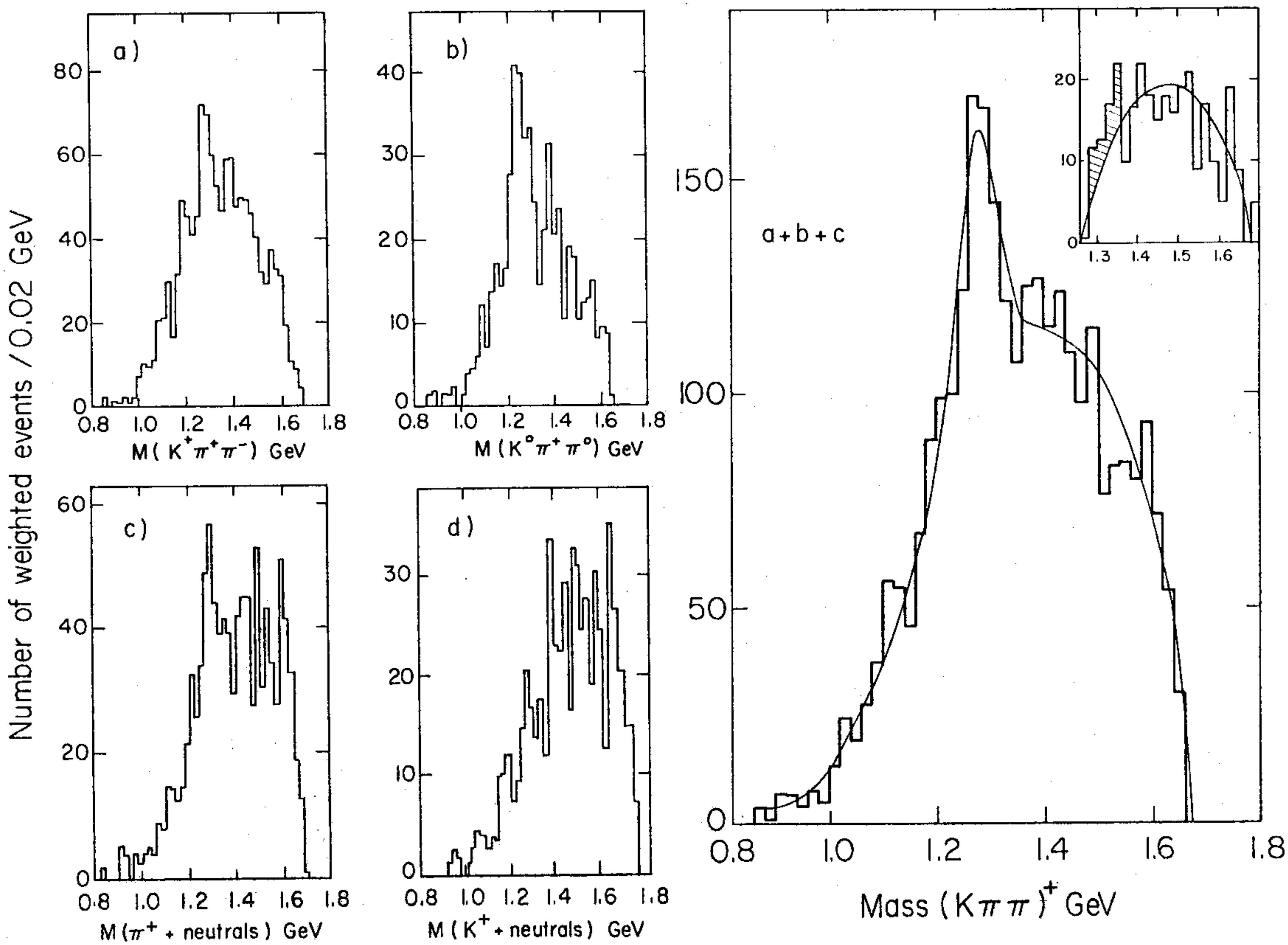
(a) Chew-Low plot for the $K^o\pi^+\pi^o$ system,

(b) $\pi^+\pi^o$ vs $K^o\pi^+\pi^o$ mass scatter plot,

(c) $K^o\pi^+$ vs $K^o\pi^+\pi^o$ mass scatter plot,

(d) $K^o\pi^o$ vs $K^o\pi^+\pi^o$ mass scatter plot.

Fig. 3 Results of the partial wave analysis. (a), (b), (c) for reactions 1(a) and (d), (e), (f) for reaction 1(b).



Number of weighted events / 0.02 GeV
a)
b)
c)
d)
a + b + c
M (K⁺π⁺π⁻) GeV
M (K°π⁺π°) GeV
M (π⁺ + neutrals) GeV
M (K⁺ + neutrals) GeV
Mass (Kππ)⁺ GeV

fig. 1

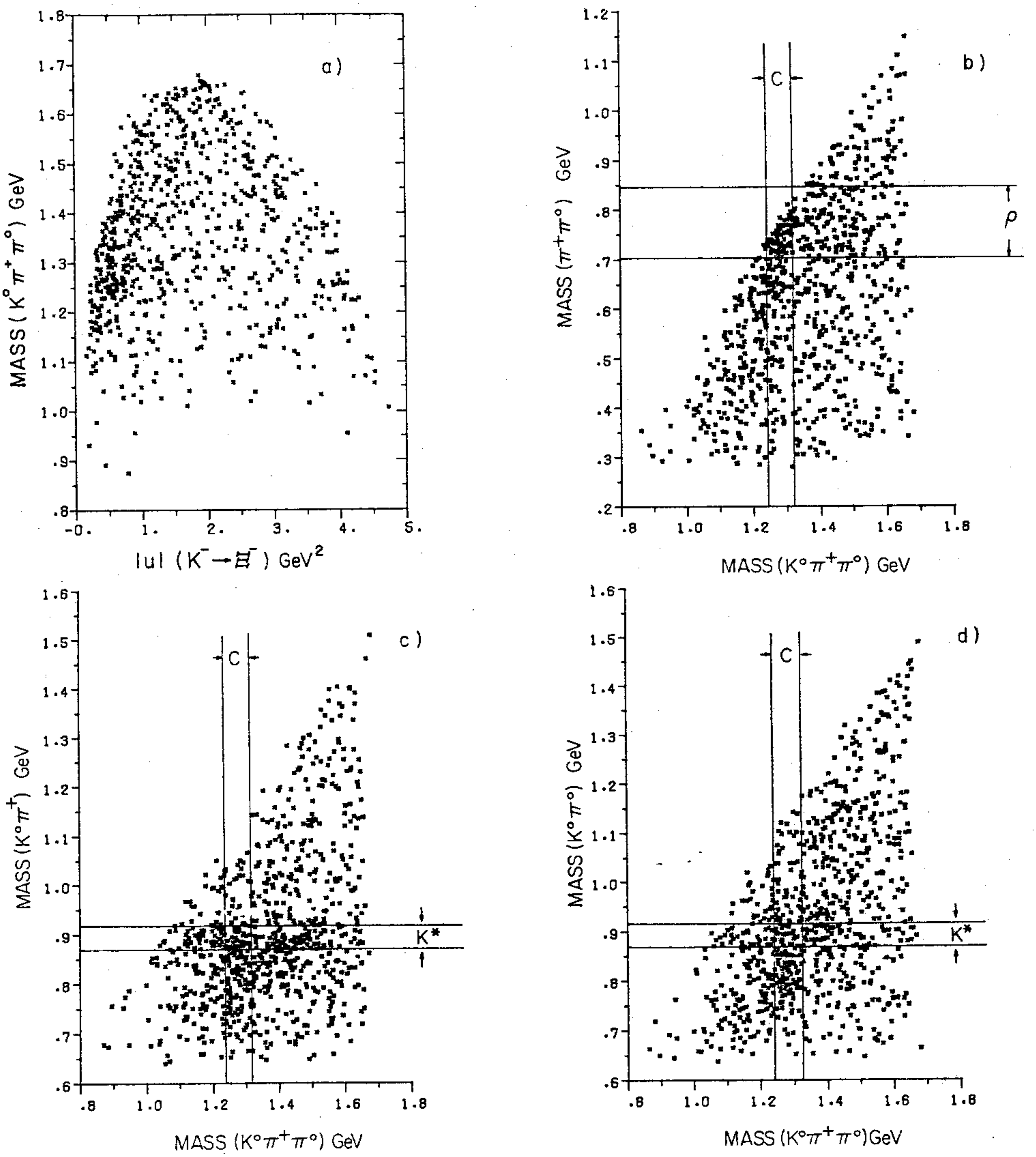
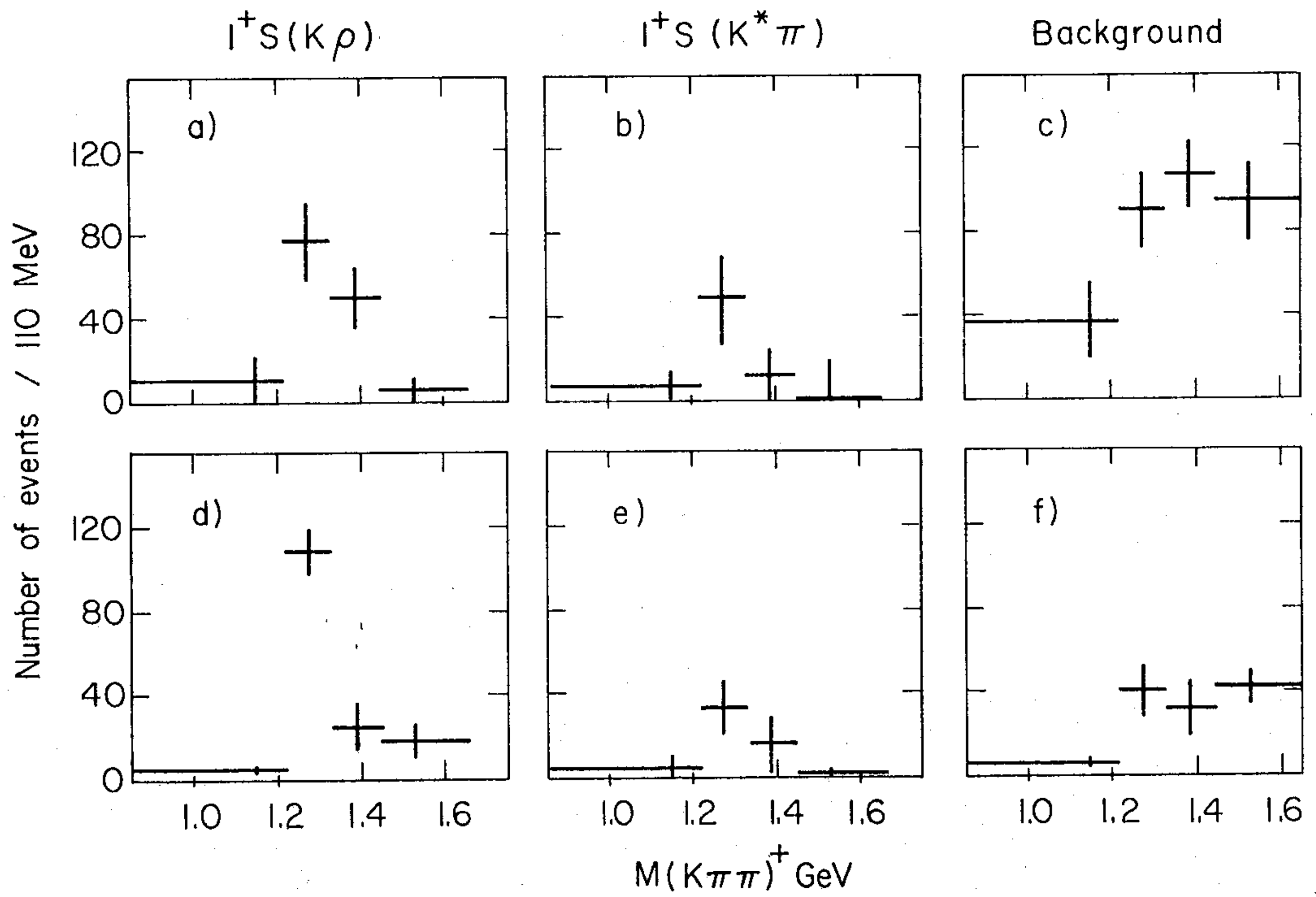

a)
MASS (K°π⁺π°) GeV
|u| (K⁻→Ξ⁻) GeV²
b)
C
ρ
MASS (π⁺π°) GeV
MASS (K°π⁺π°) GeV
c)
C
K*
MASS (K°π⁺) GeV
MASS (K°π⁺π°) GeV
d)
C
K*
MASS (K°π°) GeV
MASS (K°π⁺π°)GeV

fig. 2



I+S(Kρ)
I+S(K*π)
Background
a)
b)
c)
d)
e)
f)
120
80
40
0
1.0
1.2
1.4
1.6
Number of events / 110 MeV
M(Kππ)+ GeV

fig. 3