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DECAY ANALYSIS OF THE LOW-MASS Kππ ENHANCEMENT INTO K^*_{890} AND π-π SYSTEMS*

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ABSTRACT

The low-mass Kππ enhancement, Q, is studied in $K^+p \to K^+\pi^+\pi^-p$ and $K^+p \to K^0\pi^+\pi^0p$ interactions at 9 GeV/c. This enhancement consists of two peaks of mass and width $M = 1260 \pm 10$ MeV, $\Gamma = 40 \pm 10$ MeV and $M = 1380 \pm 20$ MeV, $\Gamma = 120 \pm 20$ MeV. The main decay modes are $K^*_{890}\pi$ and ρK, which interfere strongly. A consistent description of the data requires either an additional decay mode into K^+ plus an $I = 0$ s-wave π-π system (ϵ^0_{720}) or a large interference effect between two components of the Q, or both.

The low-mass Kππ enhancement (1.2-1.5 GeV), called the Q, has been reported to consist of one or more resonances,[1-3] a Deck-type kinematic enhancement,[4-8] or a combination of these effects. Its spin-parity has been determined to be $J^P = 1^+$,[4,9,10] and its isotopic spin has been determined to be $I = 1/2$. In the present letter we report on the internal structure of the Q enhancement and on its decay branching fractions.

The experiment was carried out with ~ 200,000 pictures taken in the Brookhaven National Laboratory's 80-inch hydrogen bubble chamber, which was exposed to a 9-GeV/c rf-separated K^+ beam at the Alternating Gradient Synchrotron. The sample studied here consists of the reactions

$$K^+p \rightarrow K^+p\pi^+\pi^- \qquad 7577 \text{ events} \qquad (1)$$

$$\rightarrow K^0p\pi^+\pi^0 \ (K^0 \rightarrow \pi^+\pi^-) \qquad 2272 \text{ events} \qquad (2)$$

$$\rightarrow K^0n\pi^+\pi^+ \ (K^0 \rightarrow \pi^+\pi^-) \qquad 462 \text{ events} \qquad (3)$$

which corresponds to about three times the data reported earlier.[9] These events have been collected in an unbiased manner from the same sample of film, which allows direct comparisons between the three reactions.

The main features of the data are the strong production of N^{*++}_{1236}, K^*_{890}, K^*_{1420}, ρ, and Q enhancements. We shall refer to the Q enhancement as being resonant in nature, however the decay analysis which follows is independent of this assumption. In Fig. 1a we show $M(K\pi\pi)$ for all the events of reactions (1) and (2). The shaded region represents events with N^{*++}_{1236} removed; this does not significantly affect the Q enhancement. For the study of the $K\pi\pi$ system we consider only events with the N^{*++}_{1236} removed. In Fig. 1b is shown $M(K\pi\pi)$ with a selection on ρ or K^*_{890}. A statistically significant split of the entire Q enhancement (an effect of >4 standard deviations at present) is observed in the data as was reported earlier.[9] The lower peak has a mass of $M = 1260 \pm 10$ MeV and a width of $\Gamma = 40 \pm 10$ MeV.[11] The upper peak is centered at a mass of $M = 1380 \pm 20$ MeV and a width of $\Gamma = 120 \pm 20$ MeV, part of which is the contribution of the decay $K^*_{1420} \rightarrow K\pi\pi$. From the reaction $K^+p \rightarrow K^{*+}_{1420}p$, $K^{*+}_{1420} \rightarrow K^0\pi^+$, in which the K^0 is visible, and using the branching ratios reported in the Tables of the Particle Data Group,[12] we calculate a contribution of 87 events to the Q enhancement from the decay $K^*_{1420} \rightarrow K\pi\pi$. In a plot of $M(K\pi\pi)$ for events with N^*_{1236}, K^*_{890} and ρ_{760} removed (not shown), no evidence is seen for any Q enhancement. The data are therefore consistent with no significant three-body $K\pi\pi$ decay of the Q. In Fig. 1c is shown $M(K\pi\pi)$ $(I = 3/2)$ for the reaction $K^+p \rightarrow K^0n\pi^+\pi^+$. No evidence is seen for any Q enhancement in this final state as expected from the $I = 1/2$ assignment of the Q.

We nevertheless estimate the possible $I = 3/2$ background contribution in the Q region. To this end we decompose the $I = 3/2$ state $K^o\pi^+\pi^+$ into the two states $(K\pi)_{I=1/2} + \pi$ and $(K\pi)_{I=3/2} + \pi$. For the $K^on\pi^+\pi^+$ events in which $M(K^o\pi^+\pi^+)$ is in the Q region, the mass distribution $M(K^o\pi^+)$ is consistent with 100% K^*_{890} production. The decay sequence $Q^{++}_{I=3/2} \rightarrow (K\pi)_{I=1/2} + \pi$ predicts a maximum of 6 events out of 377 events in the $K^o\pi^+\pi^o$ state and 7 events out of 1100 events in the $K^+\pi^+\pi^-$ state, as a result of an $I = 3/2$ amplitude in the Q region. Consequently, we shall regard the Q region as a pure $I = 1/2$ system. We also observe a peak corresponding to the L-meson[1] from 1660 MeV to 1840 MeV. This peak shows some indication of structure in the form of a "narrow spike" at ~ 1750 MeV.

In Fig. 2 is shown the scatter plots of $M(K\pi)$ vs $M(\pi\pi)$ and their projections for the final states $K^+p\pi^+\pi^-$ and $K^op\pi^+\pi^o$, where $M(K\pi\pi)$ is in the Q region. Clear evidence is seen for the decay of the Q into $K^*_{890}\pi$ and $K\rho$ states. For the K^o events there are two possible $K^*_{890}\pi$ decay modes, both of which are present. The mass projection $M(K^o\pi^o)$ (not shown) appears substantially the same as the projection $M(K^o\pi^+)$. There is a high concentration of events in the overlap regions of the K^*_{890} and ρ mesons.

For the purpose of relating reactions (1), (2), and (3) we have studied possible experimental biases. We form the ratios

$$\frac{\Gamma(K^+p \rightarrow K^{*o}_{890}\, N^{*++}_{1236} \rightarrow K^op\pi^+\pi^o)}{\Gamma(K^+p \rightarrow K^{*o}_{890}\, N^{*++}_{1236} \rightarrow K^+p\pi^+\pi^-)} \quad \text{and} \quad \frac{\Gamma(K^+p \rightarrow K^{*+}_{890}\, N^{*+}_{1236} \rightarrow K^on\pi^+\pi^+)}{\Gamma(K^+p \rightarrow K^{*o}_{890}\, N^{*++}_{1236} \rightarrow K^op\pi^+\pi^o)}$$

which are determined by I-spin conservation to be 1/2 and 2/9 respectively. The experimental ratios, in which the K^o events have been corrected for the visible decay branching ratio are in good agreement with the predictions of I-spin conservation as shown in Table I. This demonstrates the absence of any appreciable loss of one final state with respect to the other.

In order to compare the experimental data with I-spin predictions for Q decay into $K^*_{890}\pi$ and $K\rho$ states, we study a series of ratios

$$R(\frac{K^o}{K^+}) = \frac{\Gamma(K^+p \rightarrow \text{ intermediate state } \rightarrow K^op\pi^+\pi^o)}{\Gamma(K^+p \rightarrow \text{ intermediate state } \rightarrow K^+p\pi^+\pi^-)}$$

which are independent of any phase space factors. Conservation of I-spin predicts a ratio of $R(K^o/K^+) = 1$ for pure $K^*_{890} + \pi$ decay and $R(K^o/K^+) = 2$ for pure $\rho + K$ decay of the Q. To analyze the decay features as a function of $M(K\pi\pi)$, we have divided the Q into three regions; I: 1.2-1.3 GeV, II: 1.3-1.4 GeV, and III: 1.4-1.5 GeV, referred to as low Q, mid Q, and high Q. The experimental ratios are shown in Table I. We note that none of the ratios changes with $M(K\pi\pi)$, and in addition that the ratios are insensitive to the manner in which the amount of resonances was estimated (see Table I). The ratio $R(K^o/K^+)$ for the $K^*_{890}\pi$ decay mode is unity as expected from I-spin, but the ratio $R(K^o/K^+)$ for $K\rho$ decay is also unity, which is in contradiction with the predictions of I-spin. Moreover, the ratio $R(K^o/K^+)$ for all events in the Q is unity, which would imply no $K\rho$ state at all, while a strong ρ signal is seen in the mass projections (see Fig. 2). Three possible phenomena may contribute to this discrepancy: (1) interference between the $K^*_{890}\pi$ and $K\rho$ decay modes; (2) the presence of an $I = 0$ s-wave $\pi\pi$ enhancement (ϵ^o_{720}) in the $K^+\pi^+\pi^-p$ final state at about the ρ-mass, which cannot appear in the $K^o\pi^+\pi^op$ state; (3) possible mixing between different octets of two $J^P = 1^+$ Q resonances.

We have studied the interference between the $K^*_{890}\pi$ and $K\rho$ decay modes of the Q by calculating the density on the Dalitz plot for the two cases $Q^+ \rightarrow K^o\pi^+\pi^o$ and $Q^+ \rightarrow K^+\pi^+\pi^-$. For the K^o events there are two possible $K^*_{890}\pi$ decay modes and therefore the interference is different for the K^o and K^+

events. The expression for the intensity, I, on the Dalitz plot is given by[10]

$$I = \sum_{M=-1}^{+1} |A_M|^2$$

where

$$A_M = [G_{K^{*o}} Y_1^M(\theta_{K^{*o}} \varphi_{K^{*o}})\frac{2}{3} + G_\rho Y_1^M(\theta_\rho \varphi_\rho)\sqrt{1/3}\ \alpha e^{i\beta}]$$

for the K^+ events and

$$A_M = [\{(G_{K^{*o}} Y_1^M(\theta_{K^{*o}} \varphi_{K^{*o}}) - G_{K^{*+}} Y_1^M(\theta_{K^{*+}} \varphi_{K^{*+}})\}\frac{\sqrt{2}}{3} + G_\rho Y_1^M(\theta_\rho \varphi_\rho)\sqrt{2/3}\ \alpha e^{i\beta}]$$

for the K^o events, in which G is a Breit-Wigner function of the form

$$G = \frac{\sqrt{\Gamma(\frac{m}{m_o})(\frac{p_o}{p})}}{(m^2 - m_o^2) - i m_o \Gamma} \qquad \text{and} \qquad \Gamma = \Gamma_o (\frac{p}{p_o})^3 (\frac{m_o}{m}) \ .$$

The above expressions assume a spin parity $J^P = 1^+$ assignment for the Q region and an s-wave decay into a vector and a pseudoscalar meson. The angles θ and φ are the decay angles of the vector meson in its own rest frame, and $\alpha e^{i\beta}$ is the complex ratio of ρ to K^*_{890} amplitudes. Both α and β are treated as free parameters. In the expression for the Breit-Wigner form we have set $m_o = 894$ MeV and $\Gamma_o = 50$ MeV for the K^* and $m_o = 764$ MeV and $\Gamma_o = 125$ MeV for the ρ meson. Also p is the momentum of one decay product of the vector meson in the rest frame of the vector meson; p_o is its value at the center of the resonance where $m = m_o$.

From this calculation we have obtained values of α and β for which the experimental ratio $R(K^o/K^+) = 1$ for the entire Q region is reproduced, and simultaneously the detailed intensity on the Dalitz plot is correctly described (see the smooth curve in Fig. 2). Values of α and β are, however, predicted under exact SU_3 symmetry. Specifically, if the Q^+ is a member of an octet then the amplitudes for decay into $K^*\pi$ and $K\rho$ must be equal in magnitude ($\alpha = 1$)

and relatively real. On the other hand, the fitting to the data indicates that α may not be greater than 0.5, independent of β, if the ratio $R(K^0/K^+) = 1$ is to be reproduced. Insofar as the Q enhancement may be considered as a <u>single</u> $I = 1/2$ $J^P = 1^+$ object, this model does not fit the data well in the framework of SU_3 symmetry. Here, the SU_3 breaking interaction, as evident in the $K^*\pi$ to $K\rho$ mass difference, has been corrected for to first order by the proper phase space factors. A contour map over the two Dalitz plots of a sample calculation is shown in Fig. 3.

The second possible hypothesis to be considered is the existence of an $I = 0$ s-wave $\pi\pi$ enhancement in the $K^+\pi^+\pi^-$ final state at approximately the ρ mass for events in the Q region.[13] The presence of such an additional decay mode can explain the discrepancy in the ratio $R(K^0/K^+)$ and furthermore is consistent with the observed $\pi\pi$ mass projection. Specifically, for $M(K\pi\pi)$ in the mid-Q region (see Fig. 4) the observed "ρ" peak in the $K^+p\pi^+\pi^-$ final state is low ($m \sim 720$ MeV) and wide ($\Gamma \sim 180$ MeV) while the observed ρ peak in the $K^0p\pi^+\pi^0$ final state has the accepted mass ($m \sim 760$ MeV) and is relatively narrow ($\Gamma \sim 80$ MeV). We emphasize that this difference in the appearance of the ρ peak cannot be due to resolution as the $K^+p\pi^+\pi^-$ events are four-constraint four prongs, which have better resolution than the one-constraint $K^0p\pi^+\pi^0$ events. As shown in Fig. 4, in the low Q region the observed ρ mass is cut by phase space; however ρ production is still very strong here. In the high Q region ρ production seems reduced, but this effect may be related to the K^*_{1420}. We have looked at the decay angular distributions for the events in the ρ region and find that the K^0 and K^+ distributions appear different. However it is difficult to draw any quantitative conclusions from this fact due to the large backgrounds present.

The third phenomenon which may have to be taken into account in describing the Q region is the possible existence of two $J^P = 1^+$ Q mesons which are near in mass, but differ in that they belong to SU_3 octets with opposite charge conjugation quantum numbers.[14] (Presumably the lower mass Q meson would belong to the octet with $J^{PC} = 1^{++}$ containing the A_1 meson, and the higher mass Q meson would belong to the octet with $J^{PC} = 1^{+-}$ containing the B meson.) In this case a description of the data involves not only interference effects between the $K^*\pi$ and $K\rho$ decay modes of a single Q^+ meson, but may also involve an interference effect between the decay modes of the two Q^+ mesons. Furthermore an SU_3 mixing can occur between these two Q mesons, which results in an effective predicted $\alpha e^{i\beta}$ which need not be equal to ±1, and which depends on the mixing angle and the relative production rates of the two Q mesons. Even in the limit of a small mixing angle between the two Q mesons, no prediction may be made about the effective $\alpha e^{i\beta}$ since the two physical Q mesons are not well-separated in mass and the relative production amplitudes are not known. Although many aspects of the data including the ratio $R(K^0/K^+)$ may be reproduced with a value of $\alpha \approx 0.4$ and $\beta \approx 0^0$, one cannot interpret this as providing a value for the ρ/K^* branching fraction due to the complications introduced by a possible $K\epsilon^0$ decay mode and the SU_3 mixing of the two Q mesons.

We thus conclude that a consistent description of the data, including the ratio $R(K^o/K^+)$ in the Q region, and the detailed distribution on the Dalitz plot requires either the presence of the decay $Q^+ \rightarrow K^+\epsilon^o_{720}$ in the final state $K^+p\pi^+\pi^-$ or an interference effect between two different $J^P = 1^+$ objects in the Q region, or both. We emphasize that the inclusion of a general incoherent background term over the entire Dalitz plot does not contribute to an understanding of the data as the ratio $R(K^o/K^+)$ equals unity specifically in the ρ region. We further emphasize that the splitting of the observed Q peak is strong evidence for important multiple resonance contributions to this phenomenon.

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FOOTNOTES AND REFERENCES

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FIGURE CAPTIONS

Fig. 1. M(Kππ) for the final state Kpππ: (a) for final states $K^+p\pi^+\pi^-$ and $K^op\pi^+\pi^o$, the shaded region corresponds to events with N^{*++}_{1236} removed. (b) For the final states $K^+p\pi^+\pi^-$ and $K^op\pi^+\pi^o$ with N^*_{1236} removed and K^*_{890} or ρ selected. (c) For the final state $K^on\pi^+\pi^+$.

Fig. 2. Scatter plots and projections of M(Kπ) and M(ππ) for the final states $K^+p\pi^+\pi^-$ and $K^op\pi^+\pi^o$, in which M(Kππ) is in the Q region. (a) M(Kπ) vs M(ππ) for the final state $K^+p\pi^+\pi^-$. (b) M(Kπ) for the final state $K^+p\pi^+\pi^-$. (c) M(ππ) for the final state $K^+p\pi^+\pi^-$. (d) M(Kπ) vs M(ππ) for the final state $K^op\pi^+\pi^o$. (e) M(Kπ) for the final state $K^op\pi^+\pi^o$. (f) M(ππ) for the final state $K^op\pi^+\pi^o$.

Fig. 3. A contour map in 5% steps of the density distribution over the Dalitz plots.

Fig. 4. M(ππ) for the final states $K^op\pi^+\pi^o$ and $K^+p\pi^+\pi^-$ in the three regions Q-low, Q-medium, and Q-high.

Table I. Table of ratios. The K^o events have not been corrected for escape probability which amounts to a few percent.

Ratio	Number of events		Results	
	$K^+p\pi^+\pi^-$	$K^op\pi^+\pi^o$	I-spin[a]	Experimental
$K^+p \to K^{*o}_{890}N^{*++}_{1236} \to \left[\frac{K^op\pi^+\pi^o}{K^+p\pi^+\pi^-}\right]$	644	100	1/2	0.47±0.05
	($K^on\pi^+\pi^+$:	30)		
$K^+p \to \left[\frac{K^{*+}_{890}N^{*+}_{1236} \to K^on\pi^+\pi^+}{K^{*o}_{890}N^{*++}_{1236} \to K^op\pi^+\pi^o}\right]$			2/9	0.30±0.07
$K^+p \to Q^+p \to \left[\frac{K^op\pi^+\pi^o}{K^+p\pi^+\pi^-}\right]$				
1) Entire Q	1415	438		0.93±0.05
2) K^*_{890} or ρ (narrow)[b]	1100	377		1.03±0.06
3) K^*_{890} (narrow)[b]	827	262	1	0.95±0.07
4) ρ (narrow)[b]	708	260	2	1.10±0.08
5) K^*_{890} (wide) above background[c]	1116	357	1	0.96±0.06
6) ρ (wide) above background[c]	324	110	2	1.02±0.11
7) K^*_{890} or ρ outside interference region	323	112		1.04±0.11
8) low Q	504	160		0.95±0.09
9) mid Q	498	150		0.90±0.08
10) high Q	413	128		0.93±0.09
11) low Q (K^* or ρ)	387	134		1.04±0.10
12) mid Q (K^* or ρ)	395	136		1.03±0.10
13) high Q (K^* or ρ)	318	107		1.01±0.11

a. The I-spin prediction refers to the production of a single state.

b. K^*(narrow): 860-920 MeV. ρ(narrow): 680-800 MeV.

c. K^*(wide): 820-960 MeV. ρ(wide): 620-860 MeV.

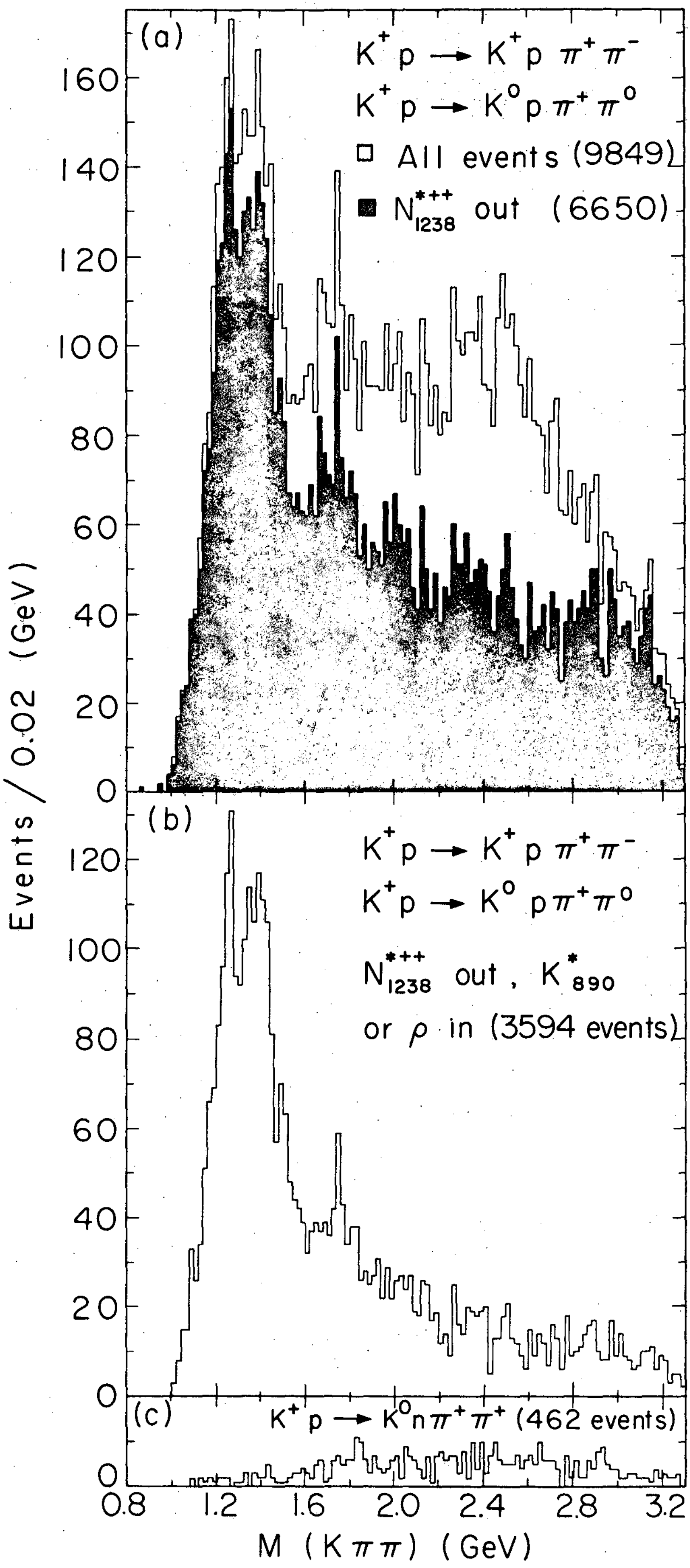

(a)
K⁺p → K⁺p π⁺π⁻
K⁺p → K⁰p π⁺π⁰
☐ All events (9849)
■ N*++ 1238 out (6650)
(b)
K⁺p → K⁺p π⁺π⁻
K⁺p → K⁰ pπ⁺π⁰
N*++ 1238 out , K*890
or ρ in (3594 events)
(c)
K⁺p → K⁰nπ⁺π⁺ (462 events)
Events / 0.02 (GeV)
M (Kππ) (GeV)
0
20
40
60
80
100
120
140
160
0.8
1.2
1.6
2.0
2.4
2.8
3.2

Fig. 1

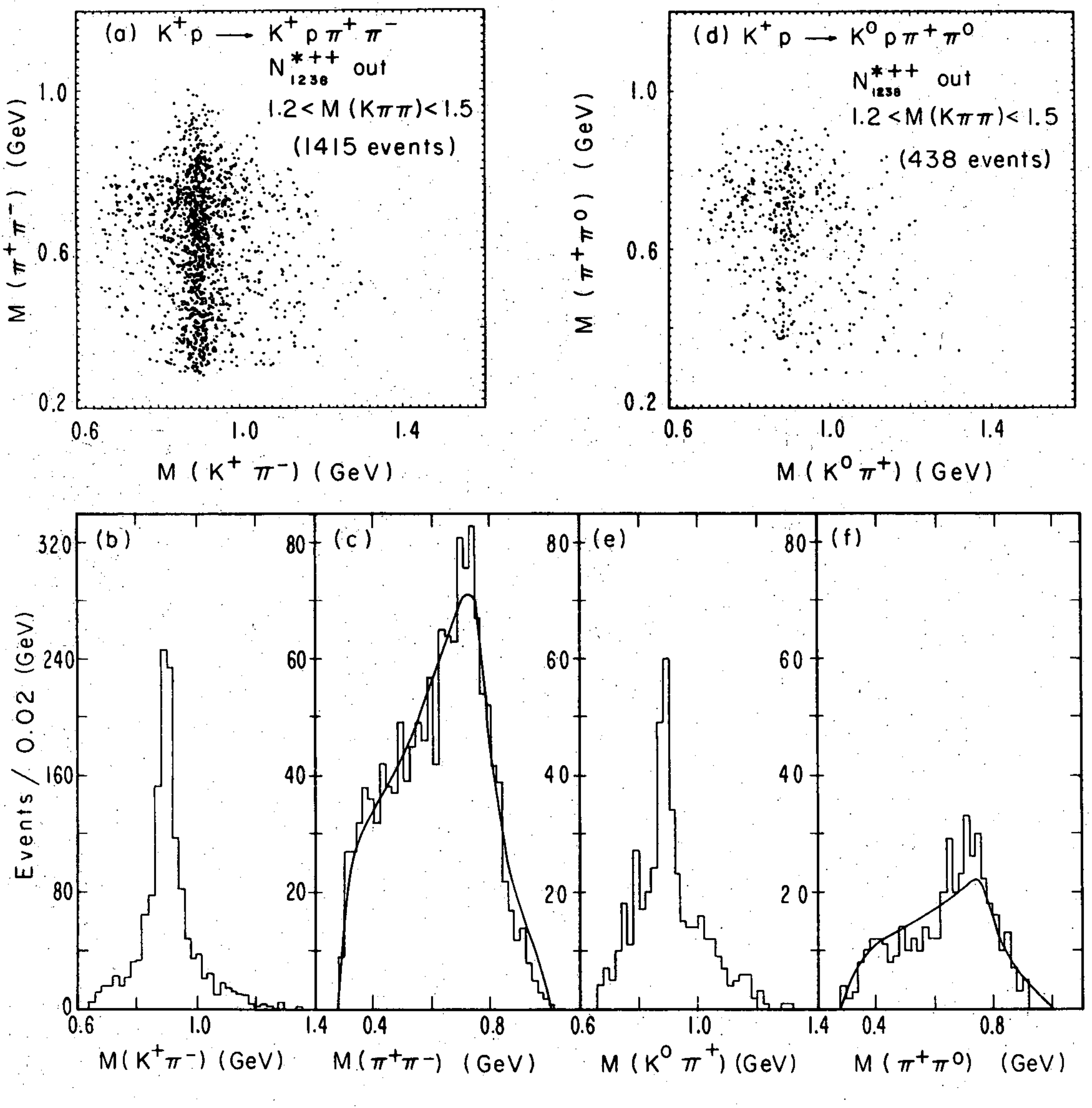
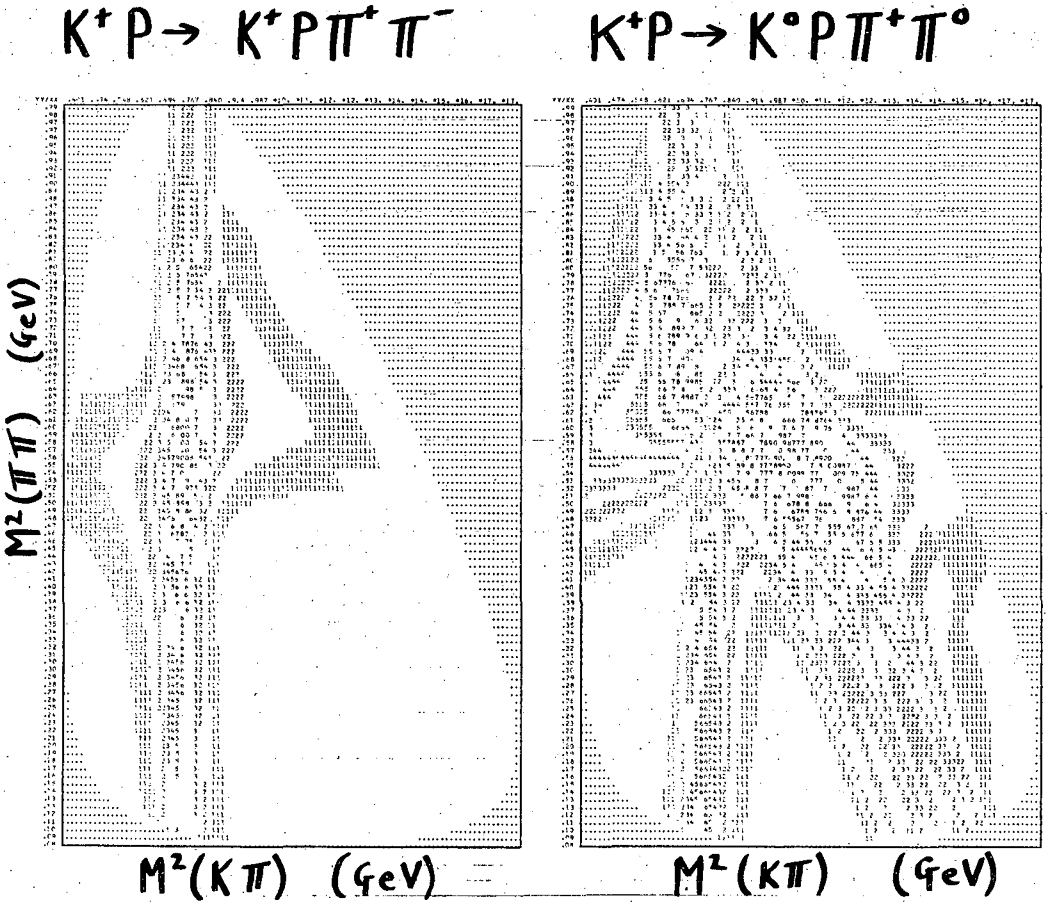
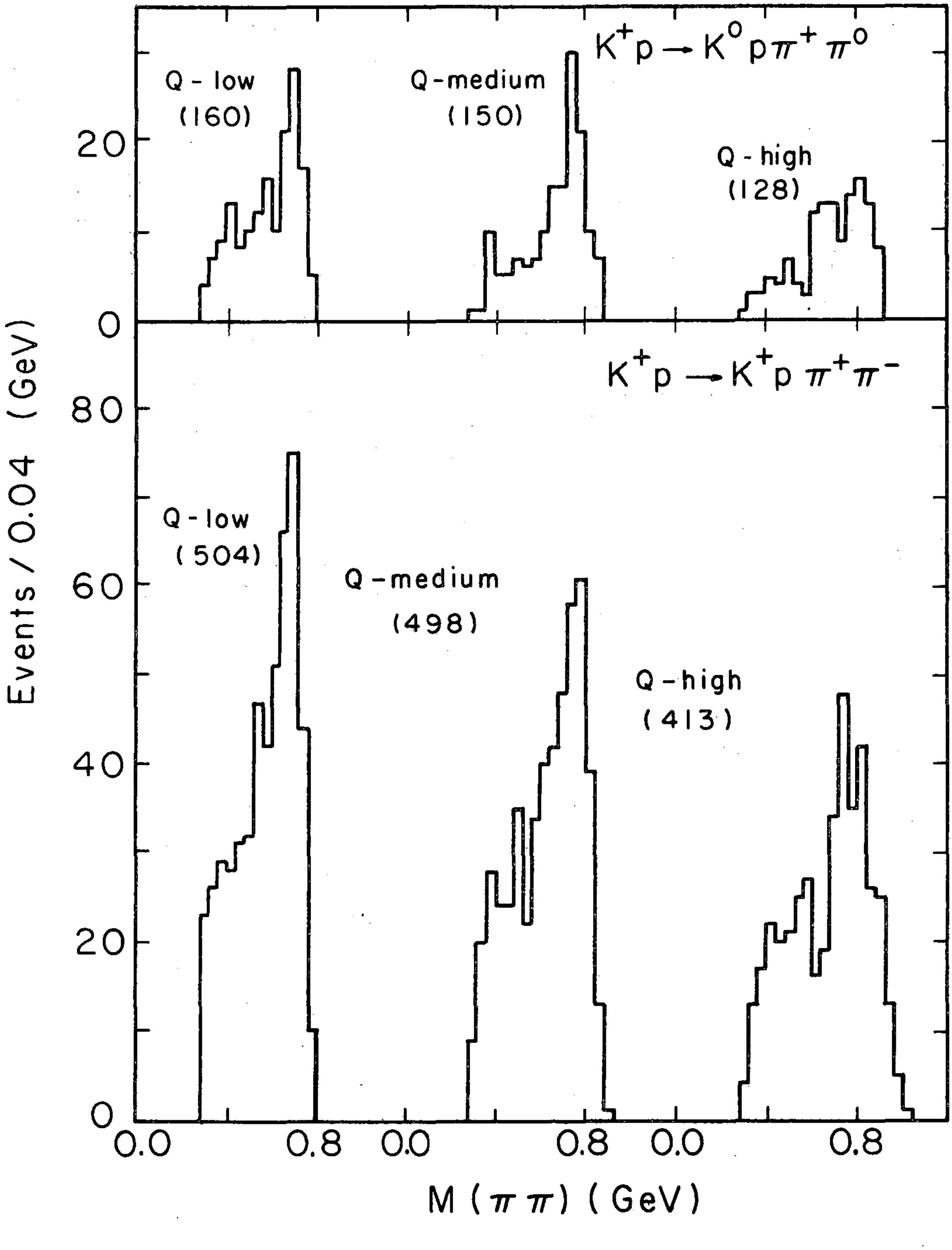

(a) $K^+p \rightarrow K^+p\pi^+\pi^-$
N^{*++}_{1236} out
$1.2 < M(K\pi\pi) < 1.5$
(1415 events)
$M(\pi^+\pi^-)$ (GeV)
$M(K^+\pi^-)$ (GeV)
(d) $K^+p \rightarrow K^0p\pi^+\pi^0$
N^{*++}_{1236} out
$1.2 < M(K\pi\pi) < 1.5$
(438 events)
$M(\pi^+\pi^0)$ (GeV)
$M(K^0\pi^+)$ (GeV)
0.2
0.6
1.0
1.4
(b)
(c)
(e)
(f)
Events / 0.02 (GeV)
0
80
160
240
320
20
40
60
80
0.8
$M(K^+\pi^-)$ (GeV)
$M(\pi^+\pi^-)$ (GeV)
$M(K^0\pi^+)$ (GeV)
$M(\pi^+\pi^0)$ (GeV)
XBL694-2486

Fig. 2



$M_Q = 1.4 - 1.5$ GeV $\alpha = 0.75$ $\beta = 0°$

Fig. 3



XBL694-2472

Fig. 4

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