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RESONANCE PRODUCTION IN MULTI-PARTICLE FINAL STATES IN K^+p INTERACTIONS AT 9 GeV/c*

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ABSTRACT

We present results on the five- and six-body final states $K^0p\pi^+\pi^+\pi^-$ and $K^0p\pi^+\pi^+\pi^-\pi^0$ in K^+p interactions at 9 GeV/c. We observe copious production of known resonances such as N^{*++}_{1236}, K^*_{890}, K^*_{1420}, ρ, and ω. In addition, there are significant mass enhancements in the A_1 and A_2 mass regions with mass and width values of $M_{A_1} = 1060\pm20$ MeV, $\Gamma_{A_1} = 160\pm20$ MeV, and $M_{A_2} = 1290\pm20$ MeV, $\Gamma_{A_2} = 50\pm10$ MeV respectively.

I. INTRODUCTION

It has been pointed out that due to the angular momentum barrier, high-mass high-spin resonances are expected to decay primarily through several steps involving lower-mass lower-spin resonances rather than to decay directly into two or three nonresonating particles.[1] Specifically, high-mass high-spin K^* mesons are expected to decay through lower-mass and lower-spin resonances such as K^*_{890} or ρ mesons rather than directly into $K\pi$ or $K\pi\pi$ states. Such K^* resonances, if they exist, could appear in the four- or five-meson mass distributions of the five- and six-body final states in K^+p interactions. At the same time, it is of interest to study the roles of the intermediate mass and spin resonances, such as K^*, ρ or the "A" mesons, in multi-particle final states. In this paper we present results of a study of the five- and six-body final states involving a visible K^o meson produced in K^+p reactions at 9 GeV/c.

The experiment has been carried out in about 200 000 exposures of the Brookhaven National Laboratory 80-inch liquid hydrogen bubble chamber to a 9-GeV/c rf-separated K^+ beam of the Brookhaven AGS. The events used in this work were four prongs and four prongs associated with a visible K^o decay. The events were measured on the LRL Flying Spot Digitizer and remeasurements were carried out on conventional digitizing machines. The events were reconstructed in space and kinematically fitted in the program SIOUX. The four-prong plus visible K^o events were fitted to the following hypotheses:

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

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

$$K^o n\pi^+\pi^+\pi^+\pi^- \qquad (3)$$

Kinematic ambiguities among these hypotheses were resolved on the scan table. In addition, those four-pronged events (without a visible K^o decay) which did not fit a four-constraint hypothesis ($K^+p \rightarrow K^+p\pi^+\pi^-$ or $K^+pK^+K^-$) were fitted to the following hypotheses:

$$K^+p\pi^+\pi^-\pi^o \quad (4)$$

$$K^op\pi^+\pi^+\pi^- \quad (5)$$

$$K^+n\pi^+\pi^+\pi^- \quad . \quad (6)$$

In many cases, these final state configurations are kinematically ambiguous at this energy. The ambiguities were resolved in part by considering only that sample of the data in which the momentum of the proton is $\leqq 600$ MeV/c. This corresponds to a cut in the four-momentum transfer of $-t_{pp} = 0.33\ (\mathrm{GeV/c})^2$. The identity of the proton at momenta below this cut is readily established using the FSD automatic ionization measurement. Remaining ambiguities in the identification of the meson tracks have been resolved as much as possible using the FSD ionization measurements. The residual ambiguous events were decided by choosing the hypothesis associated with the lowest chi-square. We estimate that this procedure introduces a maximum misidentification of 20% of the events in the final state (b) below. In this way we obtain a sample of events in the following final states:

$K^op\pi^+\pi^+\pi^-$	(visible K^o)	456 events	(a)
$K^op\pi^+\pi^+\pi^-$	(no visible K^o and $P_{prot} \leqq 600$ MeV/c)	1475 events	(b)
$K^op\pi^+\pi^+\pi^-\pi^o$	(visible K^o)	1141 events .	(c)

For this paper we consider only events in which there is a neutral K-meson. We note that the experimental ratio of visible to nonvisible K^o events is not the expected 1:2, due to the fact that different samples were used for reactions (a) and (b). In the following analysis we have combined final states (a) and (b) and refer to them as the five-body final state; (c) is referred to as the six-body final state.

In the following four sections we present the most prominent features of this data. Some of the more detailed aspects of these reactions have not been presented, as the complexity of these final states requires considerably larger statistics to obtain a greater insight into all the different channels contributing here.

II. PRODUCTION OF ESTABLISHED RESONANCES

The invariant mass distribution, $M(K^o\pi^+)$, of the five- and six-body final states is shown in Fig. 1, where two combinations per event are plotted. A strong production of K^*_{890} is seen in both final states. There is, however, very little evidence for the $K^o\pi^+$ decay of the K^*_{1420}. The origin of the small enhancement in $M(K^o\pi^+)$ below the K^*_{890} will be discussed in Sec. IV. In Fig. 2 are shown the $p\pi^+$ mass spectra where clear evidence is seen for the production of N^{*++}_{1236}. In the various two-pion mass spectra there is evidence for the production of ρ^o and $\rho^\pm$ mesons which appear above a large background (see Fig. 8). In Fig. 3 we show the neutral and singly charged $K\pi\pi$ mass spectra for the five- and six-body final states. There is clear evidence for the production of $K^*_{1420} \rightarrow K\pi\pi$, and some indication for the production of resonances in the L-meson region, $\sim$ 1640 MeV to $\sim$ 1800 MeV.

Next we study the production of A_1 and A_2 mesons in these final states.[2] Figures 4 and 5 show the $\pi^+\pi^+\pi^-$ mass spectra for the five-body final state and the $\pi^+\pi^+\pi^-$ and $\pi^+\pi^-\pi^0$ mass spectra for the six-body final state respectively. In the six-body final state the ω-meson is clearly seen in the $\pi^+\pi^-\pi^0$ mass spectrum. In all three-pion mass spectra there is clear evidence for a large enhancement in the region of the A mesons (1.0 to 1.4 GeV). Furthermore in the $\pi^+\pi^+\pi^-$ spectrum for the five-body events and in the $\pi^+\pi^-\pi^0$ spectrum for the six-body events the A_1 and A_2 mesons are well separated. Figure 6 shows the combined $\pi^+\pi^+\pi^-$ five-body spectrum and $\pi^+\pi^-\pi^0$ and $\pi^+\pi^+\pi^-$ six-body spectra for these events. From these distributions we estimate the following masses and widths for the A_1 and A_2 mesons.

$$M_{A_1} = 1060\pm20 \text{ MeV} \qquad \Gamma_{A_1} = 160\pm20 \text{ MeV}$$

$$M_{A_2} = 1290\pm20 \text{ MeV} \qquad \Gamma_{A_2} = 50\pm10 \text{ MeV} \;.$$

No attempt has been made to fit the masses and widths of the A mesons, because of the large background involved. The quoted mass and width for the A_2 meson refer to the entire A_2 region as seen in this experiment. The observed mass of the A_2 meson is located at a value consistent with the center of the entire unresolved A_2 region.[3] However, the observed width is significantly narrower than that reported for the unresolved A_2 region. Statistics do not permit us to ascertain whether the observed peak corresponds to both parts of the split A_2 meson or to only one of the two parts. The production of A_2 mesons in K^+p interactions is of special interest in that it may involve an $A_2 K\bar{K}$ vertex, which has been discussed recently in connection with the splitting of the A_2.[4] A multiperipheral diagram for A_2 production in K^+p interactions in which the A_2 emerges from the interior vertex, and in which the exchanged particle from the baryon vertex is a Pomeranchukon, must have an exchange of the A_2 meson at the meson vertex (see Fig. 7). All other low-lying exchanges are prohibited by spin-parity, isotopic spin, or G-parity conservation. Figure 8 shows the neutral and singly charged two-pion mass spectra for the five- and six-body final states. The shaded regions refer to those events in which the three-pion mass is in the A-meson region. The ρ meson appears considerably enhanced in the region of the A meson. It is worthwhile to point out that in these final states the ρ meson appears above a large background in comparison with similar A-meson production final states in πp collisions where the $\rho\pi$ dominates the A region. The production of the A_1 meson in $\pi p \rightarrow \pi\pi\pi N$ interactions has been discussed frequently in terms of a diffraction scattering mechanism (Deck effect), which is expected to produce an enhancement in the A_1 mass region.[5] The production of the A_1 meson in five- and six-body final states in K^+p interactions, where a Deck effect is less likely than in $\pi N \rightarrow \pi\pi\pi N$ interactions, tends to support a resonance interpretation for the A_1 meson, where the A mesons could be the decay products of higher mass K^* resonances (see next section). However, the complicated nature of these final states does not allow us to completely rule out a nonresonant kinematical enhancement.

III. STRANGE MULTIMESON STATES

In Fig. 9a is shown the $K^o\pi^+\pi^+\pi^-$ mass spectrum for the five-body events. There is no compelling evidence for any new mass enhancement. Figure 9b shows the $K^o\pi^+\pi^-\pi^o$ mass spectrum for the six-body final state. The shaded region refers to those events for which the mass plotted, $M(K^o\pi^+\pi^-\pi^o)$, occurs with the $p\pi_2^+$ mass in the N^*_{1238} band. In Fig. 10 are shown the combined $K\pi\pi\pi$ spectra for the five- and six-body events where the $K\pi\pi\pi$ mass for the six-body events is taken against the N^*_{1238}. In Fig. 11a is shown the five-meson mass distribution for the six-body final state. Figure 11b shows the same data where only events in which the $\pi^+\pi^-\pi^o$ mass is in the "A" meson region have been plotted and Fig. 11c shows the same data where only events in which either the $\pi^+\pi^-\pi^o$ mass is in the "A" meson region or the $K^o\pi^+$ mass is in the K^*_{890} region. In all three distributions there is an enhancement at mass 2640 MeV and with a width of about 80 MeV. At the present level of statistics we are unable to ascertain the nature of this enhancement.

In view of the evidence for an enhancement in the $\overline{\Lambda}N$ mass distribution at about 2240 MeV, reported earlier in the reaction $K^+p \rightarrow \overline{\Lambda}NN(\pi)$ at 9 GeV/c,[6] we have looked for a corresponding effect in the present data. No significant enhancement is observed in either the $K\pi\pi\pi\pi$ or $K\pi\pi\pi$ mass distributions, Figs. 11 and 10 respectively, although a small enhancement cannot be ruled out in the $K\pi\pi\pi$ mass distribution.

IV. STUDY OF THE $K^o\pi^+$ SYSTEM

The combined $K^o\pi^+$ mass distribution for the five- and six-body final states $K^op\pi^+\pi^+\pi^-$ and $K^op\pi^+\pi^+\pi^-\pi^o$ is shown in Fig. 12, in which two combinations per event are plotted. In addition to the strong K^*_{890} production we also observe a low mass enhancement around 740 MeV. A similar enhancement has been observed by Ferro-Luzzi et al. in the five-body final state $K^op\pi^+\pi^+\pi^-$ at 3 GeV/c, which was discussed at that time in terms of the so-called kappa meson.[7] In both our data and in the data of Ferro-Luzzi et al. this low mass enhancement does not appear to be merely a statistical fluctuation. In Fig. 13 we plot the $K^o\pi^+$ distribution for those events associated with the N^{*++}_{1238} production. In Fig. 13a we plot that $M(K^o\pi^+)$ combination for which the <u>other</u> π^+-meson is part of the N^{*++}_{1236} and in Fig. 13b we plot the $M(K^o\pi^+)$ for which the <u>same</u> π^+-meson is part of the N^{*++}_{1236} resonance. From this figure it is clearly seen that the origin of the low mass enhancement is from that $K^o\pi^+$ combination in which the pion simultaneously forms an N^{*++}_{1236} with the proton. On the other hand, this enhancement is absent in the $K^o\pi^+$ combination where it is the other π^+-meson which is part of the N^{*++}_{1236}. Consequently we interpret the "kappa" effect as observed in this reaction to be a kinematical reflection associated primarily with N^{*++}_{1236} production. A similar result, associating the kappa effect with N^{*++}_{1238} production, has been reported by Brandt et al.[8] in the reaction $\pi^+p \rightarrow K^o\overline{K^o}\pi^+p$ at 8 GeV/c. We have searched for evidence for a similar kappa effect in the analogous four-body state $pK^o\pi^+\pi^o$, but have found no such effect.

V. DISCUSSION AND CONCLUSIONS

The study of many-particle systems in high energy interactions is made difficult by kinematical ambiguities and the reduced effectiveness of ionization measurements. This difficulty has been overcome in this experiment by imposing a unique identification requirement on at least one outgoing particle; either a visible K^o decay or a slow readily-identified proton. Since, at high energies, peripheral mechanisms appear to dominate, the selection of slow protons leaves a substantial fraction of events available for analysis.

We observe in the five- and six-body events copious production of known resonances; in particular K^*_{890}, N^{*++}_{1236}, and ρ in the two-body mass systems, and K^*_{1420}, ω, A_1, and A_2 mesons in the three-body mass systems. The absence of clear A_1 or A_2 production in the $\pi^+\pi^+\pi^-$ system in the six-body final state is probably due to the fact that at least one of the π^+ mesons is part of either the $K^*_{890} \rightarrow K^o\pi^+$ or the $N^{*++}_{1236} \rightarrow p\pi^+$ (see Figs. 1 and 2). The observed mass and width for the A_1 meson are consistent with previously reported values.[9] The width of the A_2 meson observed in this experiment is somewhat less than the average of those previously reported for the unresolved entire A_2 meson region. However, the observed mass value does not allow us to decide whether to associate this peak with A_2^L, A_2^H, or the entire unresolved A_2 meson. In order to verify the conjecture that production of A_2 mesons in K^+p interactions proceeds through a multiperipheral diagram involving an $A_2K\bar{K}$ vertex with Pomeranchuk exchange, it will be necessary to study the behavior of this final state as a function of incident momentum.

In this work we have shown that the low mass enhancement in the $K^o\pi^+$ mass system centered at about 740 MeV, and sometimes associated with the "kappa-meson effect," is a kinematic consequence of the π^+ meson being in an N_{1236}^{*++}. We emphasize that this mechanism does not explain the "kappa" effect seen in reactions such as $\pi^-p \rightarrow YK\pi$. Finally, in the five-meson system we observe a peak at 2640 MeV, which is enhanced under the selection of A mesons or K_{890}^*. While this peak is statistically significant ($\sim 4\sigma$), the nature of the enhancement is uncertain at the present time.

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FIGURE LEGENDS

Fig. 1. Mass distribution, $M(K^o\pi^+)$, two combinations per event, for the final states (a) $K^op\pi^+\pi^+\pi^-$ and (b) $K^op\pi^+\pi^+\pi^-\pi^o$.

Fig. 2. Mass distribution, $M(p\pi^+)$, two combinations per event, for the final states (a) $K^op\pi^+\pi^+\pi^-$ and (b) $K^op\pi^+\pi^+\pi^-\pi^o$.

Fig. 3. Neutral and singly-charged mass distribution, $M(K\pi\pi)$, two combinations per event, for the final states (a) $K^op\pi^+\pi^+\pi^-$ and (b) $K^op\pi^+\pi^+\pi^-\pi^o$.

Fig. 4. Mass distribution, $M(\pi^+\pi^+\pi^-)$ for the final state $K^op\pi^+\pi^+\pi^-$.

Fig. 5. Mass distributions (a) $M(\pi^+\pi^-\pi^o)$, two combinations per event, and (b) $M(\pi^+\pi^+\pi^-)$ for the final state $K^op\pi^+\pi^+\pi^-$.

Fig. 6. Combined neutral and singly-charged mass distributions, $M(\pi\pi\pi)$, for the final states $K^op\pi^+\pi^+\pi^-$ and $K^op\pi^+\pi^+\pi^-\pi^o$. The shaded region refers to the combined five-body $M(\pi^+\pi^+\pi^-)$ and six-body $M(\pi^+\pi^-\pi^o)$ distributions.

Fig. 7. A multiperipheral diagram for the production of A_2 mesons in the reaction $K^+p \rightarrow K^+p\ A_2$ with a Pomeranchuk exchange at the baryon vertex.

Fig. 8. Neutral and singly-charged mass distributions, (a) $M(\pi^+\pi^-)$ for the final state $K^op\pi^+\pi^+\pi^-$ and (b) $M(\pi^+\pi^o)$ for the final state $K^op\pi^+\pi^+\pi^-\pi^o$. The shaded areas correspond to events lying in the "A" meson regions (1.0 GeV $\leq M(\pi\pi\pi) < 1.4$ GeV). For the six-body events a similar distribution is observed for the mass $M(\pi^-\pi^o)$.

Fig. 9. Neutral and singly-charged mass distributions, $M(K\pi\pi\pi)$ for the final state (a) $K^op\pi^+\pi^+\pi^-$. The high mass part of this distribution (above 2.6 GeV/c) is due to the events in which the K^o is visible in the bubble chamber. The cut in the square of the four-momentum transfer to the proton in the one-constraint events results in a cut in the four-meson mass at about 2.6 GeV/c; and for the final state (b) $K^op\pi^+\pi^+\pi^-\pi^o$. The shaded region corresponds to events in which the other π^+ meson forms an N^{*++}_{1238} with the proton.

Fig. 10. Combined neutral and singly-charged mass distributions, $M(K\pi\pi\pi)$, for the final states $K^o p\pi^+\pi^+\pi^-$ and $K^o p\pi^+\pi^+\pi^-\pi^o$, in which, for the six-body events the mass distribution $M(K^o\pi^+\pi^-\pi^o)$ is produced together with an N^{*++}_{1238}.

Fig. 11. Mass distributions $M(K^o\pi^+\pi^+\pi^-\pi^o)$ for the final state $K^o p\pi^+\pi^+\pi^-\pi^o$: (a) all events, (b) "A" mesons selected, and (c) K^*_{890} or "A^o" mesons selected.

Fig. 12. Combined mass distribution $M(K^o\pi^+)$, two combinations per event, for the final states $K^o p\pi^+\pi^+\pi^-$ and $K^o p\pi^+\pi^+\pi^-\pi^o$.

Fig. 13. Combined mass distributions $M(K^o\pi^+)$ with $N^{*++}_{1238} \rightarrow p\pi^+$ decay selection for the final states $K^o p\pi^+\pi^+\pi^-$ and $K^o p\pi^+\pi^+\pi^-\pi^o$. (a) $M(K^o\pi^+_{other})$, (b) $M(K^o\pi^+_{decay})$.

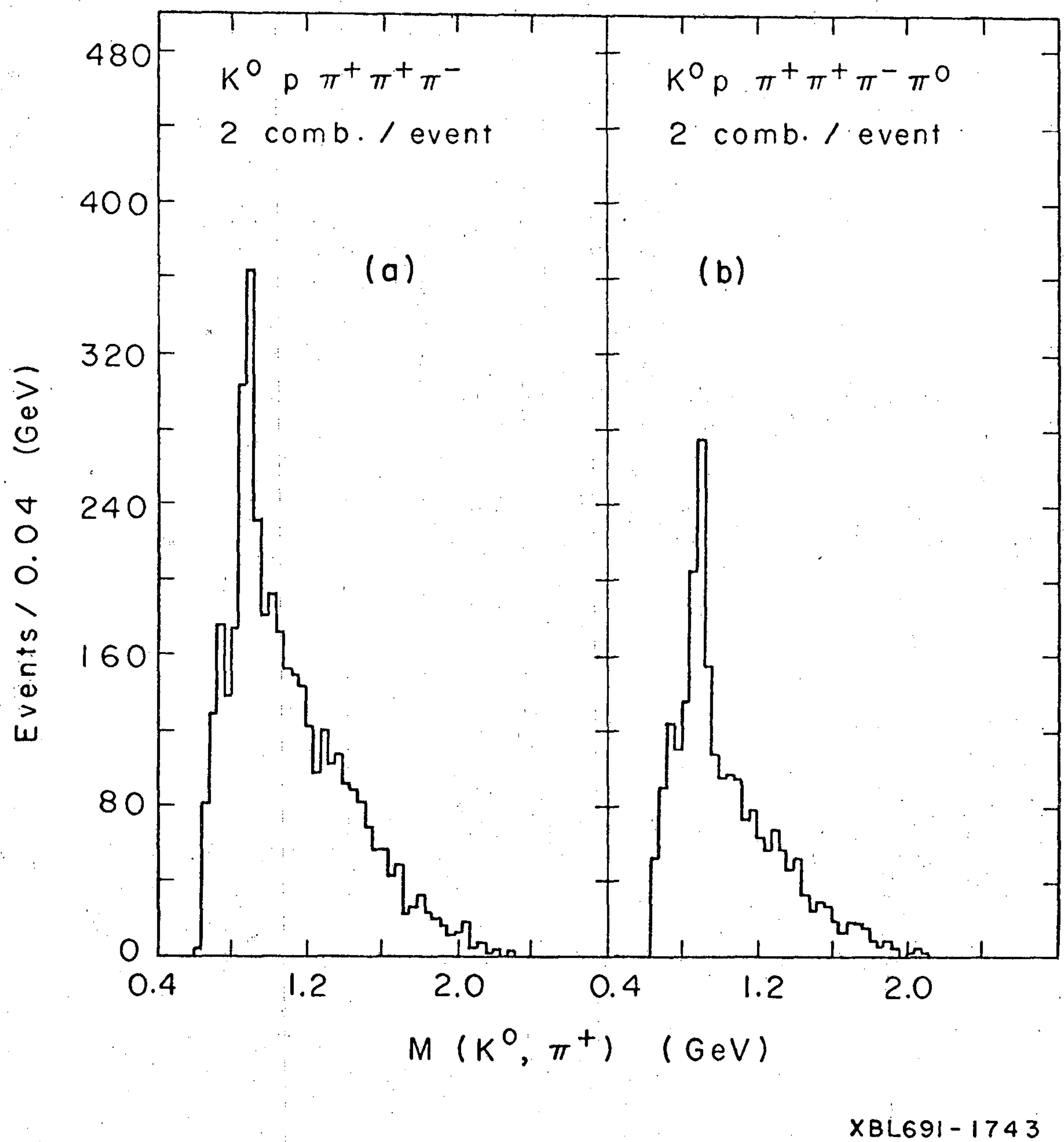
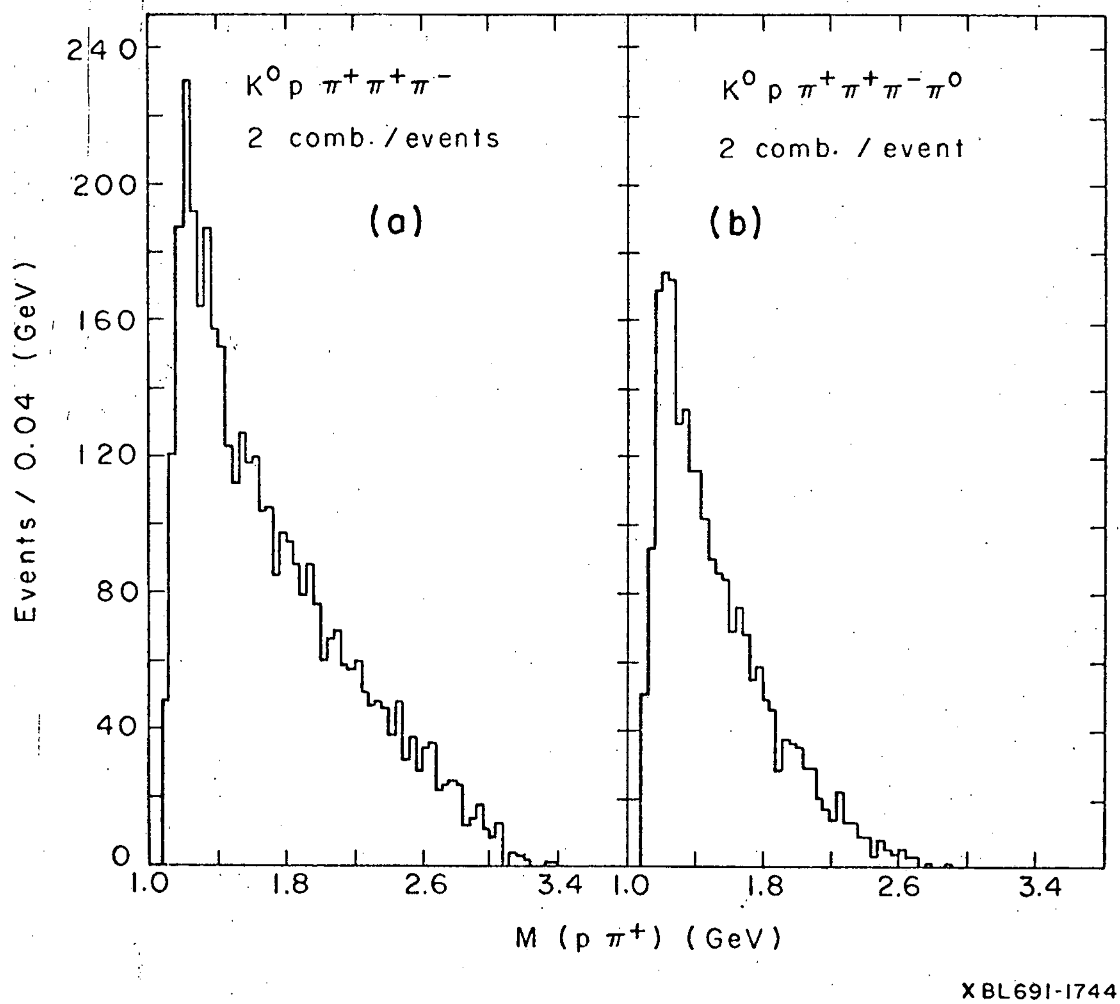

$K^0 p \pi^+\pi^+\pi^-$
2 comb. / event
(a)
$K^0 p \pi^+\pi^+\pi^-\pi^0$
2 comb. / event
(b)
Events / 0.04 (GeV)
0
80
160
240
320
400
480
0.4
1.2
2.0
0.4
1.2
2.0
M (K^0, π^+) (GeV)
XBL691-1743

Fig. 1



$K^0 p \pi^+\pi^+\pi^-$
2 comb. / events
(a)
$K^0 p \pi^+\pi^+\pi^-\pi^0$
2 comb. / event
(b)
Events / 0.04 (GeV)
0
40
80
120
160
200
240
1.0
1.8
2.6
3.4
1.0
1.8
2.6
3.4
$M(p\pi^+)$ (GeV)
XBL691-1744

Fig. 2

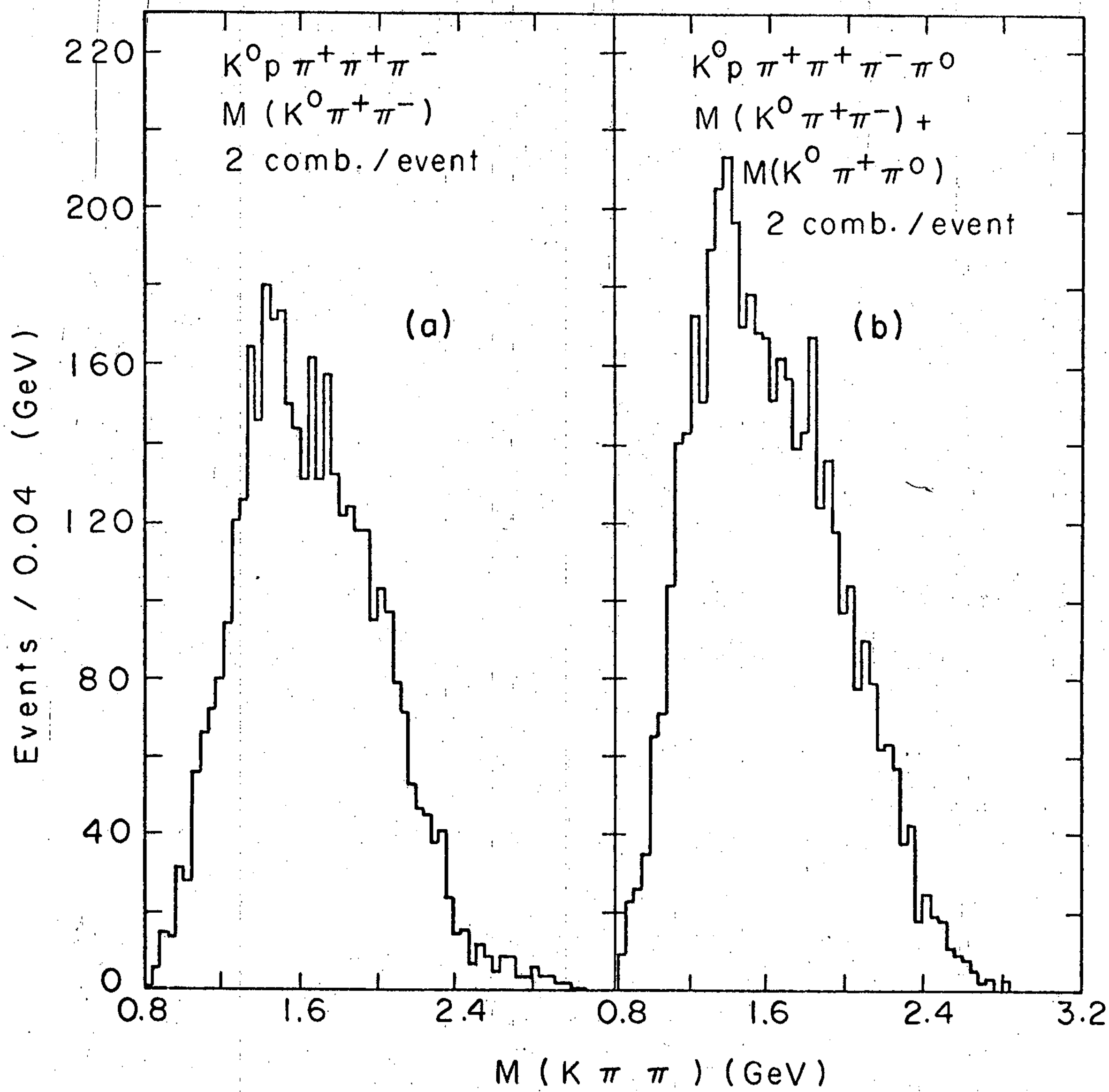


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Fig. 3

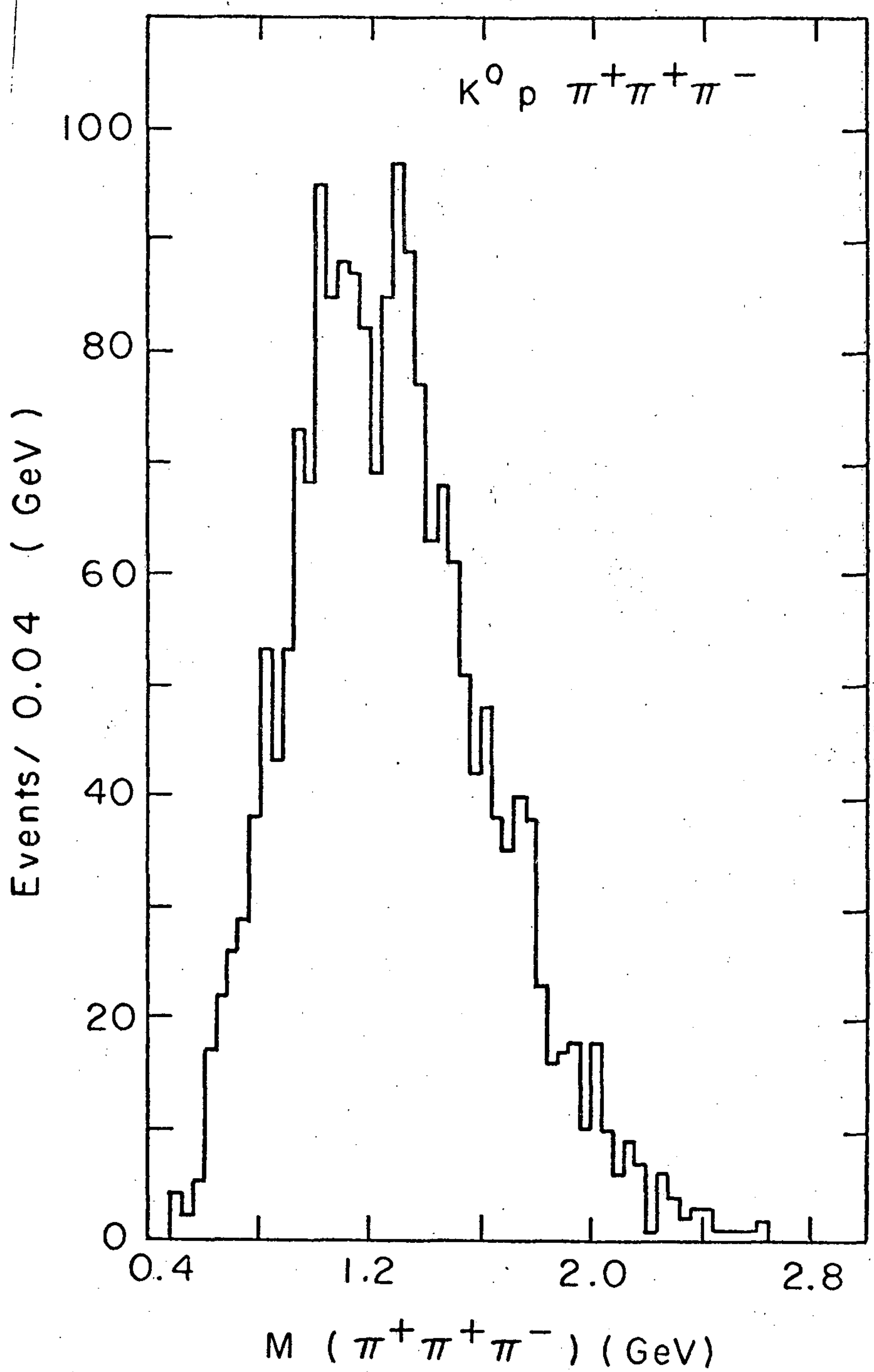

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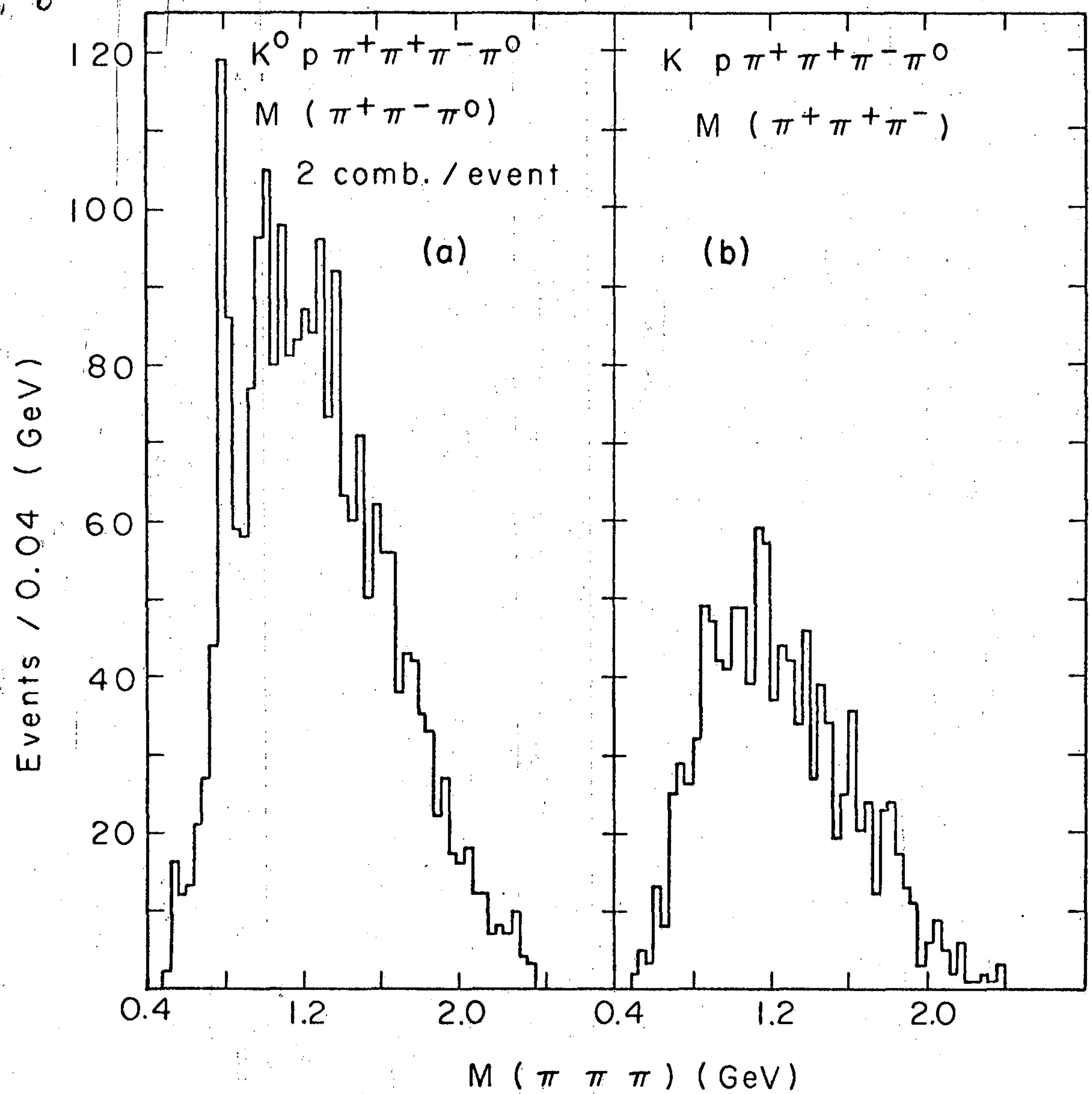
Fig. 4



XBL691-1742

Fig. 5

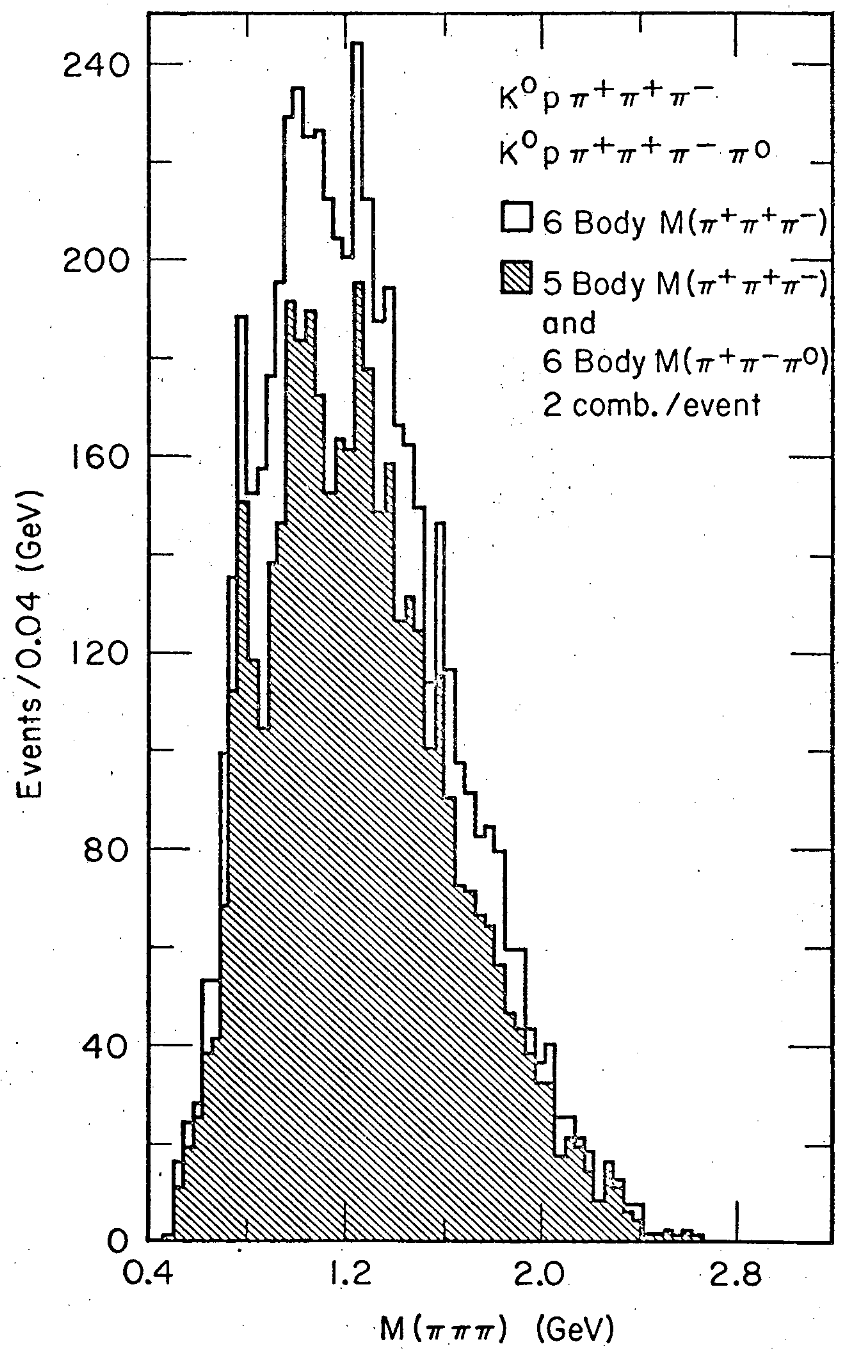


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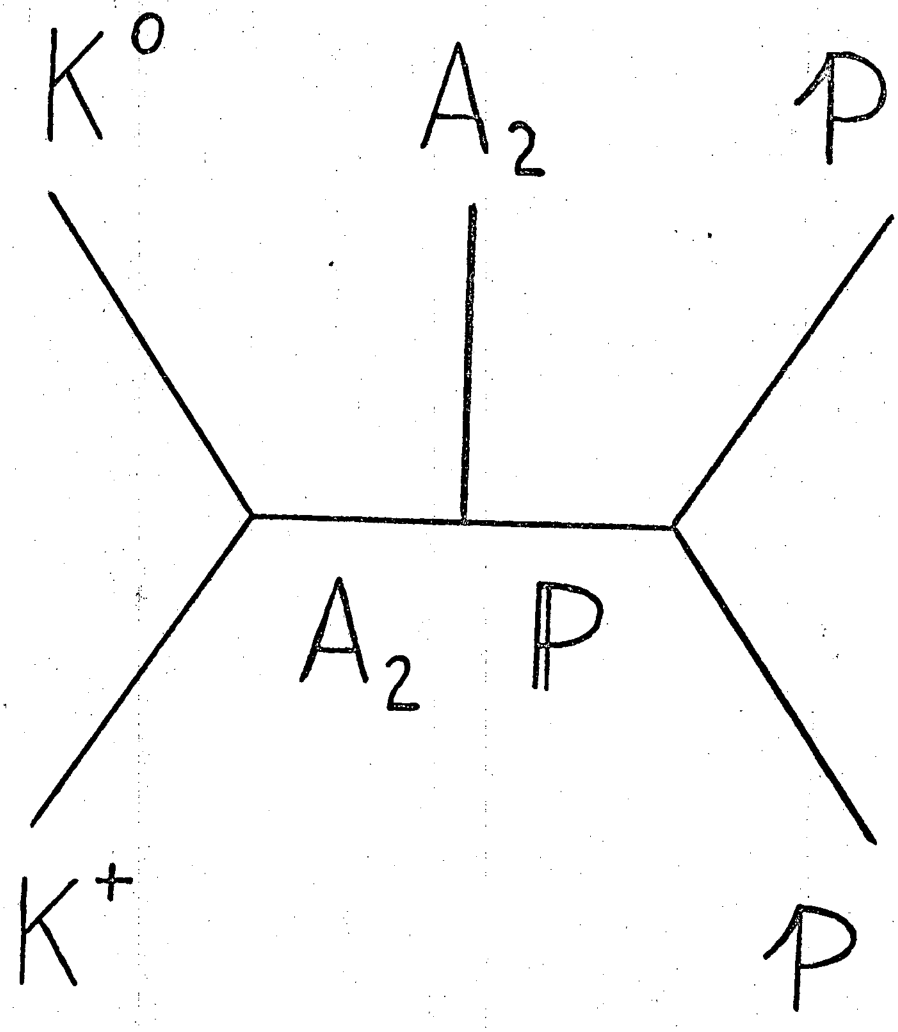
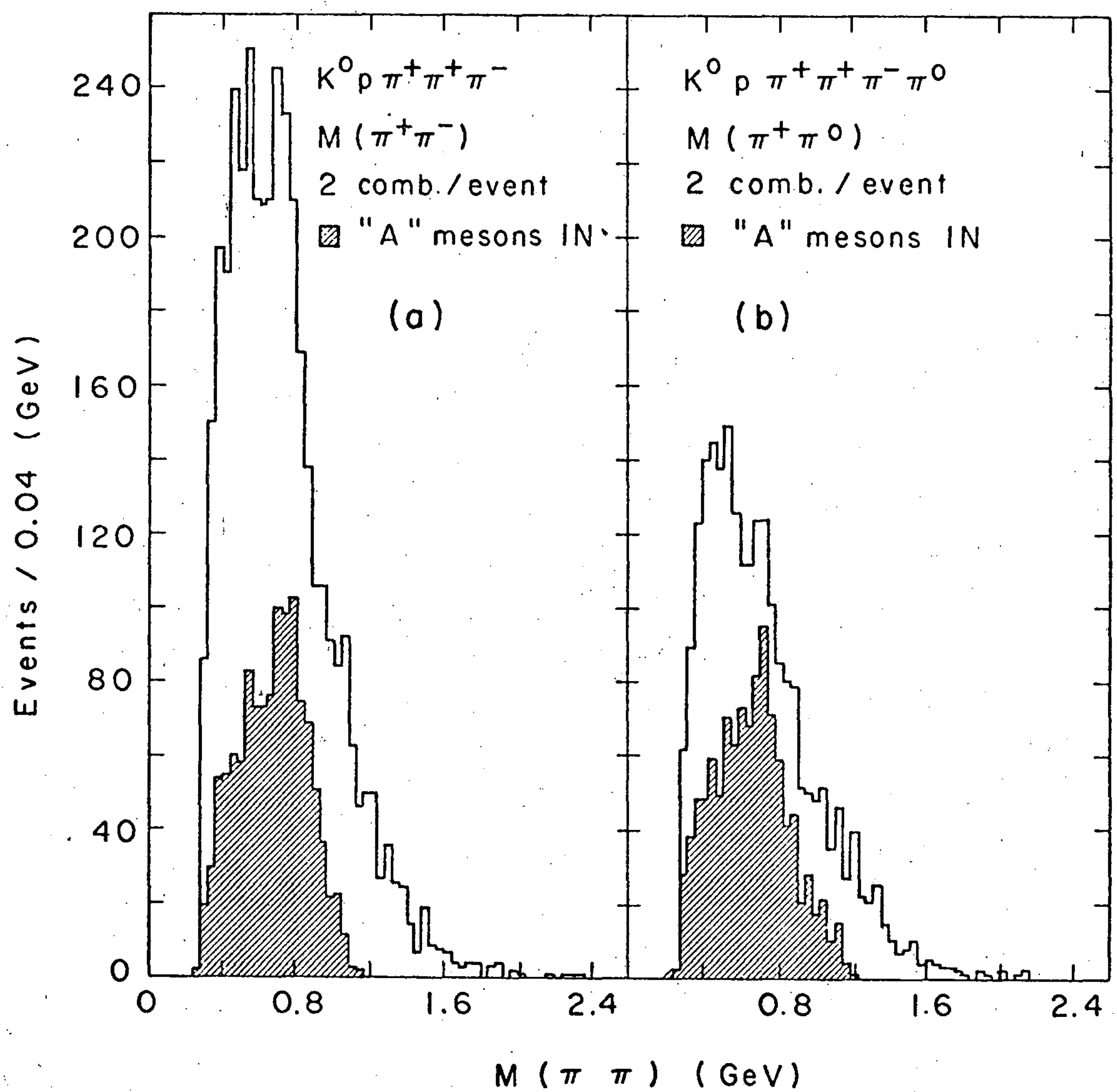
Fig. 6



XBL 692-238

Fig. 7



$K^0 p \pi^+ \pi^+ \pi^-$
$M(\pi^+\pi^-)$
2 comb./event
"A" mesons IN
(a)
$K^0 p \pi^+ \pi^+ \pi^- \pi^0$
$M(\pi^+\pi^0)$
2 comb./event
"A" mesons IN
(b)
Events / 0.04 (GeV)
0
40
80
120
160
200
240
0
0.8
1.6
2.4
0.8
1.6
2.4
M (π π) (GeV)
XBL 691- 1746

Fig. 8

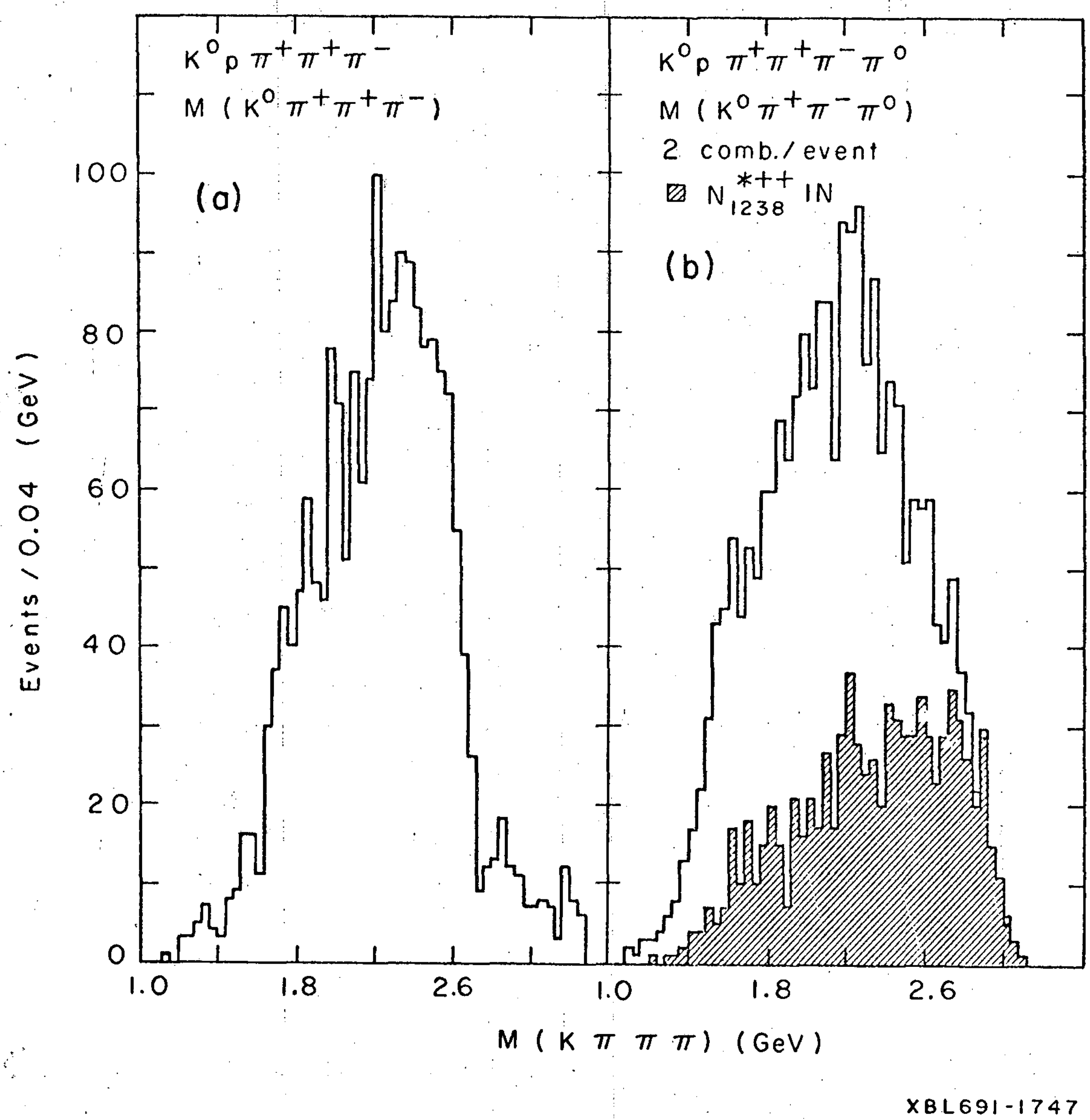
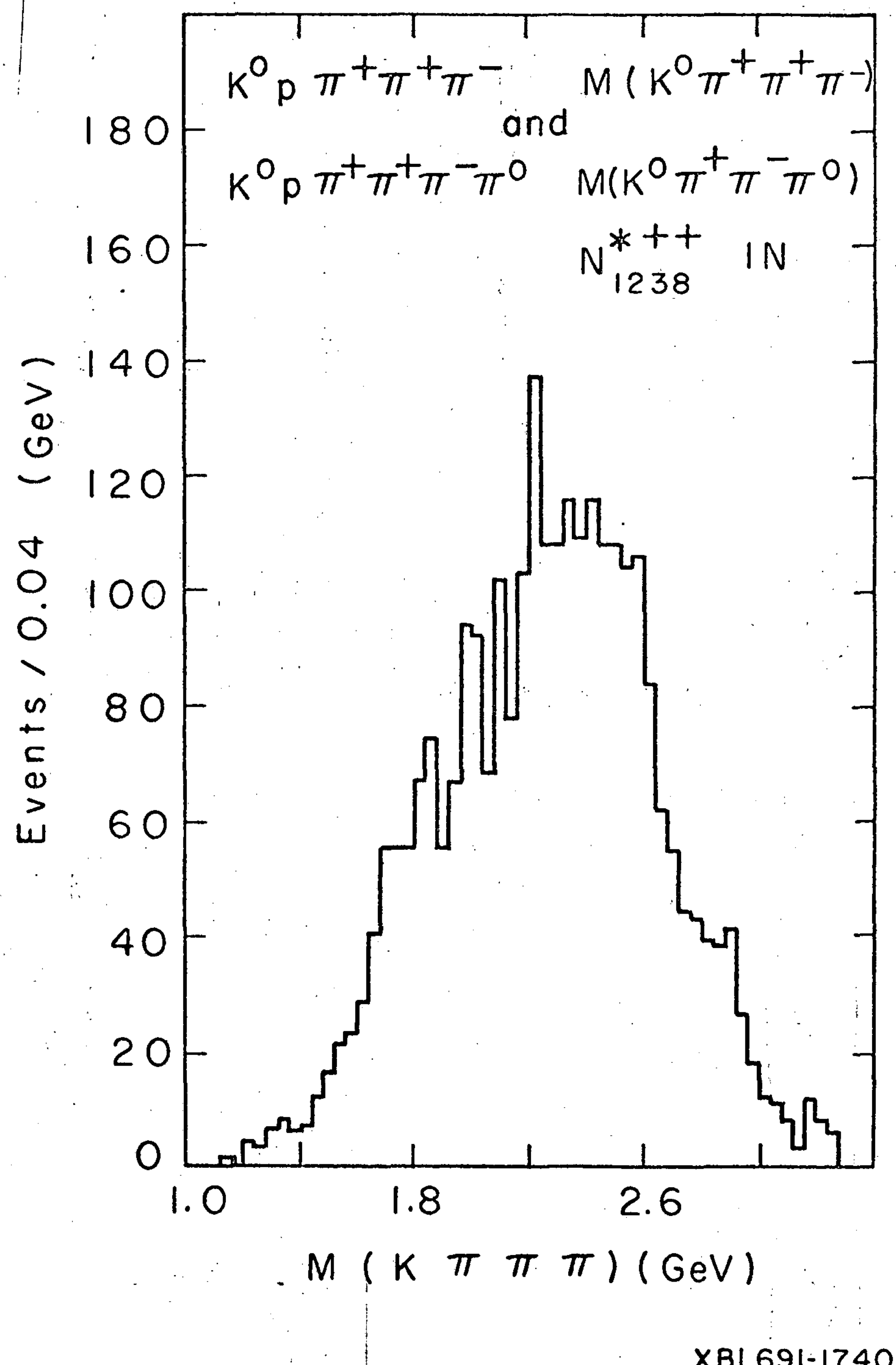
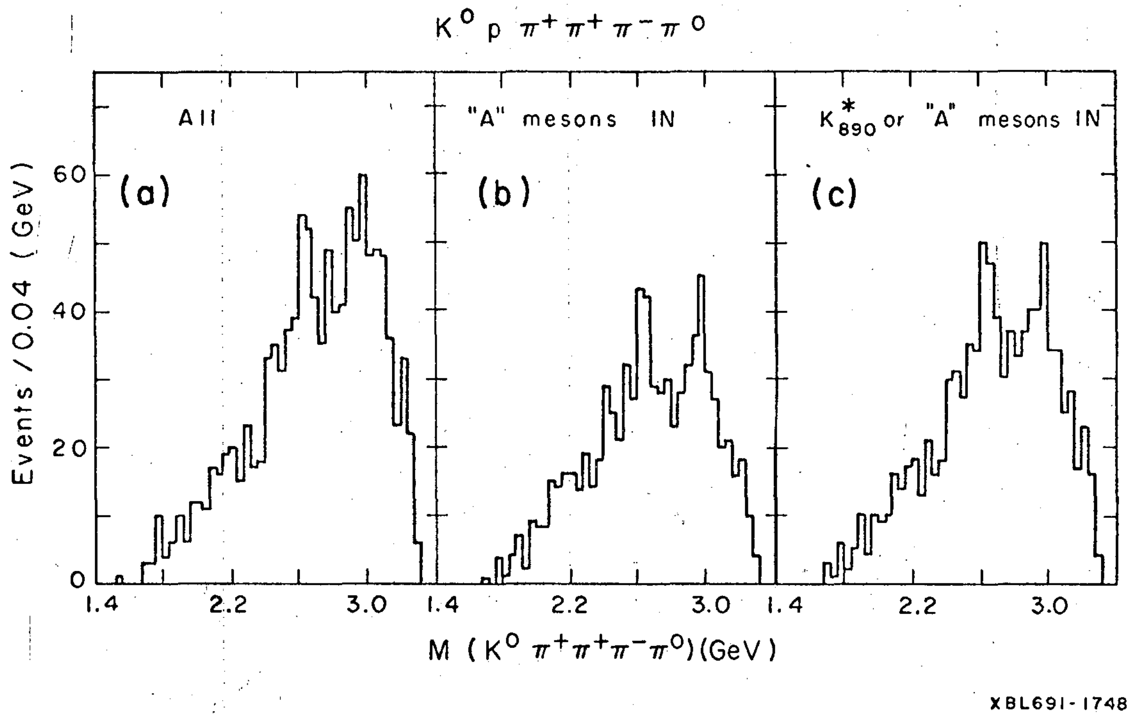

$K^0 p \pi^+\pi^+\pi^-$
$M(K^0\pi^+\pi^+\pi^-)$
(a)
$K^0 p \pi^+\pi^+\pi^-\pi^0$
$M(K^0\pi^+\pi^-\pi^0)$
2 comb./event
N^{*++}_{1238} IN
(b)
Events / 0.04 (GeV)
100
80
60
40
20
0
1.0
1.8
2.6
M (K π π π) (GeV)
XBL691-1747

Fig. 9



K0 p π+π+π− and M(K0π+π+π−)
K0 p π+π+π−π0 M(K0π+π−π0)
N*++ 1238 IN
Events / 0.04 (GeV)
180
160
140
120
100
80
60
40
20
0
1.0
1.8
2.6
M (K π π π) (GeV)
XBL691-1740

Fig. 10



$K^0 p \pi^+\pi^+\pi^-\pi^0$
All
"A" mesons IN
K^*_{890} or "A" mesons IN
(a)
(b)
(c)
Events / 0.04 (GeV)
0
20
40
60
1.4
2.2
3.0
M ($K^0 \pi^+\pi^+\pi^-\pi^0$)(GeV)
XBL691-1748

Fig. 11

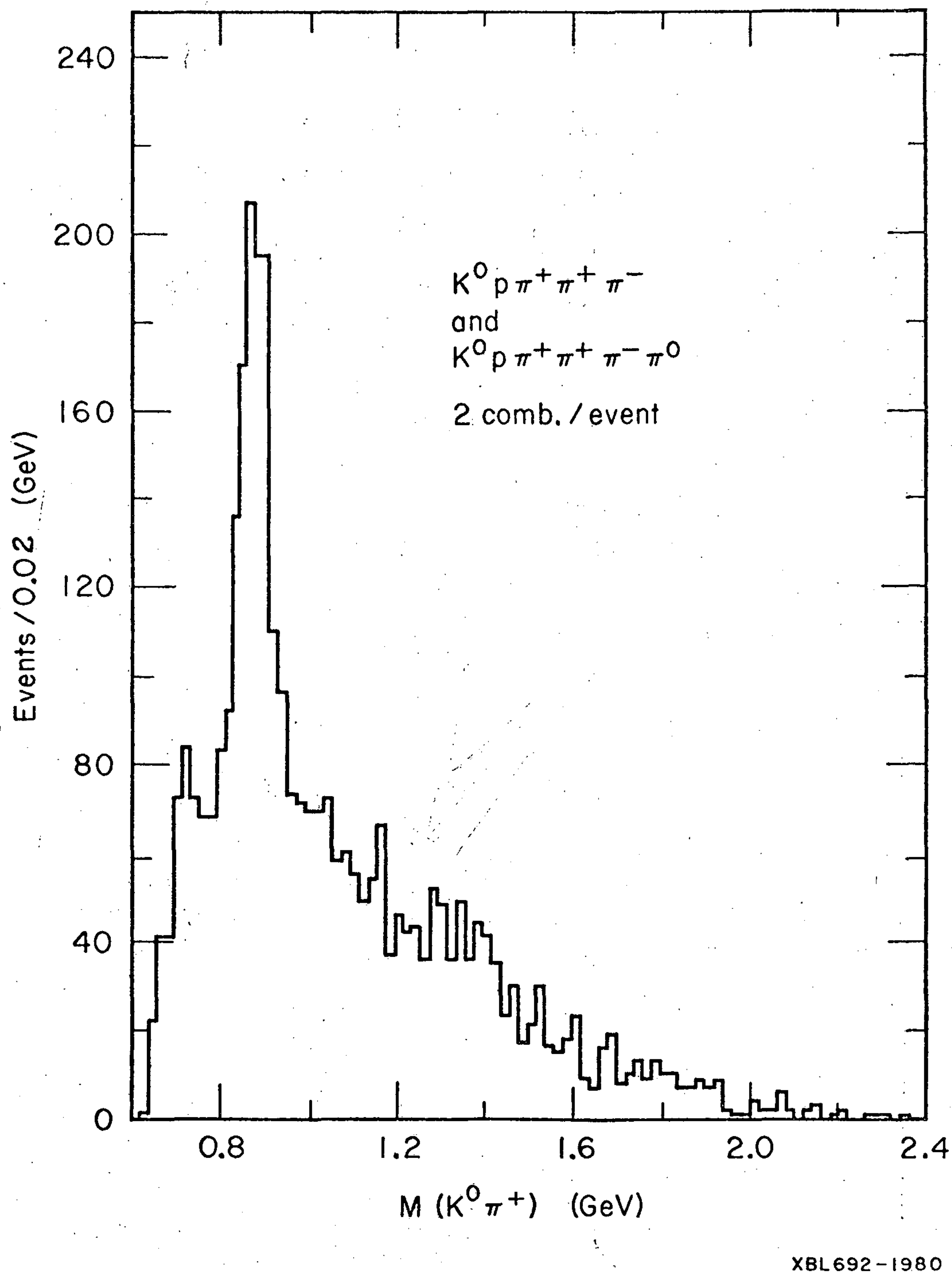
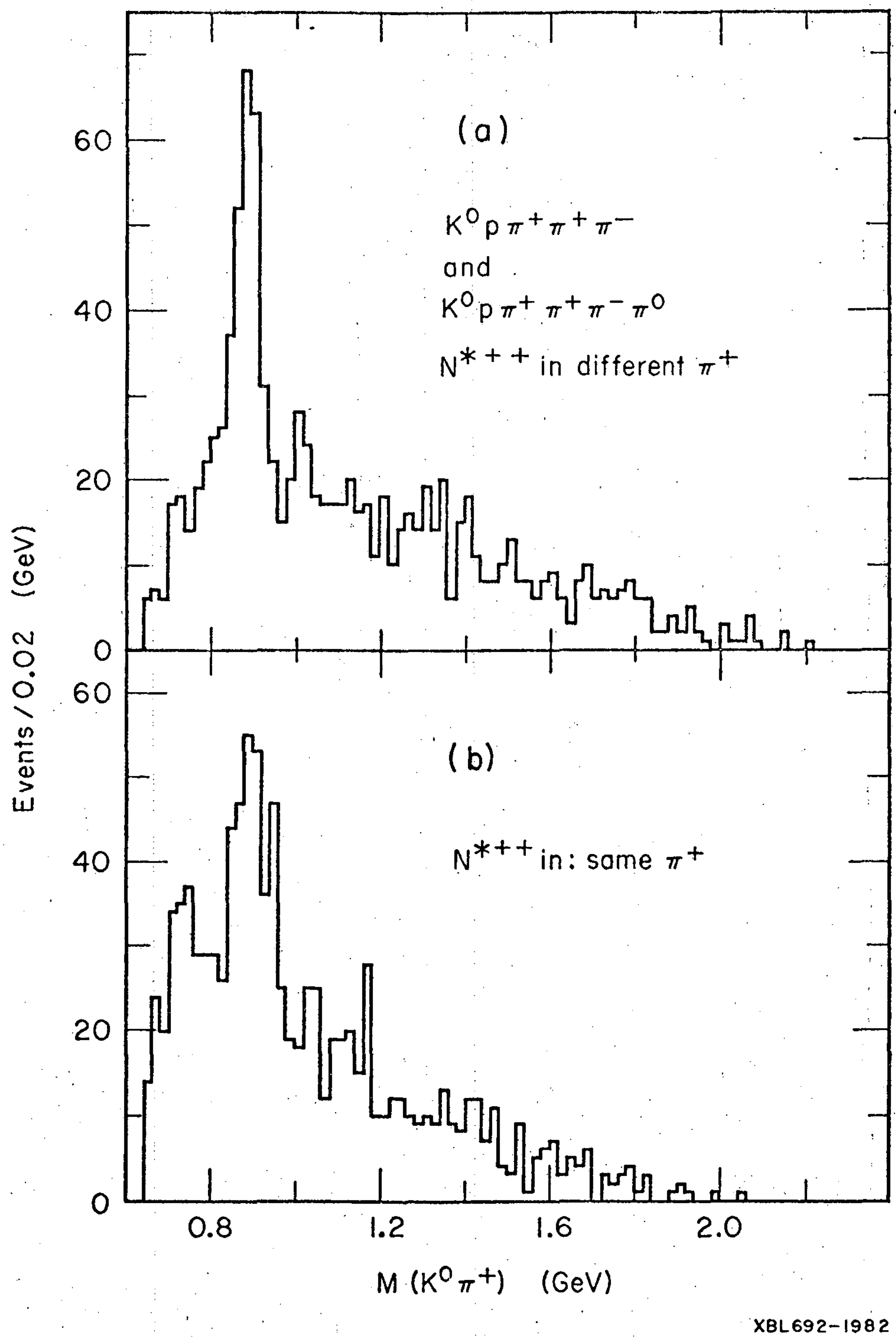

240
200
160
120
80
40
0
Events / 0.02 (GeV)
$K^0 p \pi^+ \pi^+ \pi^-$
and
$K^0 p \pi^+ \pi^+ \pi^- \pi^0$
2 comb. / event
0.8
1.2
1.6
2.0
2.4
M ($K^0 \pi^+$) (GeV)
XBL692-1980

Fig. 12



(a)
$K^0 p \pi^+ \pi^+ \pi^-$
and
$K^0 p \pi^+ \pi^+ \pi^- \pi^0$
N^{*++} in different π^+
(b)
N^{*++} in: same π^+
Events / 0.02 (GeV)
60
40
20
0
0.8
1.2
1.6
2.0
M ($K^0\pi^+$) (GeV)
XBL692-1982

Fig. 13