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October 1969

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EVIDENCE AGAINST A_1 PRODUCTION IN HIGH ENERGY K^+p INTERACTIONS*

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Abstract

The production of the A_1 has been reported at 12.8 GeV/c in the reaction $K^+p \to Kp(3\pi)$. It has also been reported at 9.0 GeV/c in the reactions $K^+p \to Kp(3\pi)$ and $K^+p \to Kp(4\pi)$. At 12.0 GeV/c, with five times the data of the 12.8 GeV/c experiment and three times the data of the 9.0 GeV/c experiment we see no evidence for A_1 production in any of these reactions.

The A_1 enhancement[1] has been seen mainly in the reaction $\pi^\pm p \to A_1^\pm p$, $A_1 \to \rho^0\pi^\pm$, $\rho^0 \to \pi^+\pi^-$, where its interpretation as a resonance has been questioned because Deck or other diffraction processes may be present.[2] In K^+p interactions, where A_1 simulating effects of this type are probably not so prominent, the observation of the A_1 would greatly favor the resonance interpretation independently of the concept of duality.[2]

Recently, observations of the A_1 have been reported in the reactions

$$K^+p \to K^+p\pi^+\pi^-(\pi^0) \quad \text{(Ref. 3)} \qquad (1)$$

$$\rightarrow K^0 p\pi^+\pi^+\pi^- \quad \text{(Refs. 3, 4)} \tag{2a}$$

$$\rightarrow (K^0) p\pi^+\pi^+\pi^- \quad \text{(Ref. 4)} \tag{2b}$$

$$\rightarrow K^0 p\pi^+\pi^+\pi^-(\pi^0) \quad \text{(Ref. 4)} \tag{3}$$

in bubble chamber experiments at 12.8 (Ref. 3) and 9.0 (Ref. 4) GeV/c (the brackets indicate a particle not detected). In our experiment at 12.0 GeV/c, we have studied these reactions with a path length corresponding to about 35 events/microbarn -- at least three times as great as in either of the other experiments.[5]

All our events were measured on a Spiral Reader, which, in addition to the coordinate measurements, gave track ionization density information useful in selecting among possible kinematic hypotheses. For each kinematic fit a bubble density chi-square (χ_B^2) was calculated, and fits to reactions (1), (2b), and (3), which have one constraint, were considered only if their χ_B^2 was no more than three greater than the best χ_B^2 for all hypotheses tried, including missing-mass calculations.[6] The most probable reaction was defined to be that reaction with the lowest sum of kinematic χ^2 and bubble density χ^2.

Reaction (1)

To make comparisons with other bubble chamber experiments more meaningful we feel that it is necessary to state the criteria used in selecting our sample of events for the study of reaction (1). We required that:
(a) There be no four-constraint fit to the event with a confidence level greater than 10^{-5}. (b) Reaction (1) be the most probable reaction and have a kinematic confidence level of at least 10^{-3}. (c) In case of a final-state ionization ambiguity between the identities of the K^+ and the proton, the proton be taken to be that track with the lower momentum.[7] (d) The square of the

four-momentum transferred between the target and final state proton, $|t_{pp}|$, be less than 1.0 GeV^2.

The main ambiguities resulting from this selection involved the identities of the $\pi^{\overset{+}{0}}$ and $K^{\overset{+}{0}}$. Some events of reaction (2b) were included in the sample of events of reaction (1), whereas some events of reaction (1) were excluded from our sample and called events of reaction (2b). In addition, the identities of the π^+ and K^+ were interchanged in some of the events in our sample of reaction (1). By taking events of reaction (2a), ignoring the existence of the visible K^0 decay, and refitting them kinematically, we were able to estimate that 8% of the events in our sample of reaction (1) came from reaction (2b). By passing Monte Carlo generated events[8] through our reconstruction and kinematic fitting programs, we found that for 10 to 20% of the events of reaction (1) the wrong permutation of the identities of the final state π^+ and K^+ was used.[9] We have examined the effects of these ambiguities and believe that they do not qualitatively affect the shapes of any of the distributions in our data.

The evidence presented for the production of the A_1 in reaction (1) in the University of Rochester experiment at 12.8 GeV/c (Ref. 3) (hereafter referred to as UR) was based upon three observations: (1) the observation of a peak in the three-pion mass spectrum between 950 and 1150 MeV; (ii) the enhancement of this peak when events were selected from the periphery of the three-pion Dalitz plot with the requirement that at least one $(2\pi)^{\pm}$ mass combination be consistent with the decay of a $\rho^{\pm}$ meson; (iii) the presence of a $\rho^{\pm}\pi^{\mp}$ signal and absence of a $\rho^0\pi^0$ signal in the vicinity of the A_1 and no ρ signal of any kind in the sum of two control regions, above and below the A_1. We consider each of these three topics in turn.

The three-pion mass spectrum for the events passing our selection criteria is shown in Fig. 1a. We observe a broad plateau extending from 1.0 to 1.3 GeV, but no narrow peak at 1.0 GeV corresponding to that seen by UR.[10] Our results may be quantitatively compared with those of UR [Fig. 1(b) of Ref. 3; $|t_{pp}| \leq 1.0$ GeV^2] by minimizing the χ^2 sum

$$\chi^2 \equiv \sum_i \frac{(A_i R - B_i)^2}{A_i R^2 + B_i} ,$$

where A_i is the number of events in the ith bin of the $M(3\pi)$ histogram of UR, and B_i is the number of events in the corresponding bin of the $M(3\pi)$ histogram for this experiment. The parameter R is the ratio of the total numbers of events in the two histograms, and is varied to minimize χ^2. For the region $0.85 \leq M(3\pi) \leq 2.0$ GeV we obtain R = 0.21 and $\chi^2 = 61.7$ for 22 degrees of freedom -- a confidence level of 10^{-5}.[11] The disagreement comes from two regions: $0.9 \leq M(3\pi) \leq 1.1$ GeV and $1.65 \leq M(3\pi) \leq 2.0$ GeV. The discrepancy at higher mass is most likely the result of a scanning bias by UR against higher-momentum protons.[12]

To better approximate the conditions of UR, Fig. 1b shows the events of Fig. 1a with the restriction that $|t_{pp}| \leq 0.3$ GeV^2. The dots in Fig. 1b represent the data of UR multiplied by 2.6. The agreement between the two sets of data in the region $1.3 \leq M(3\pi) \leq 2.0$ GeV is striking. In the ω region, the disagreement could be a result of the better mass resolution of this experiment, and beyond $M(3\pi) = 2.0$ GeV it is because we excluded all our events with $|t_{pp}| > 0.3$ GeV^2 from Fig. 1b. For the region $0.85 \leq M(3\pi) \leq 2.0$ GeV we obtain R = 2.60 and $\chi^2 = 23.1$ for 22 degrees of freedom -- a confidence level of 0.40. Even in the small region around the A_1, $0.9 \leq M(3\pi) \leq 1.2$ GeV, we have

R = 2.55 and χ^2 = 7.18 for five degrees of freedom -- a confidence level of 0.21. This means that the UR data are in statistical agreement with an experimental distribution containing more than two and a half times the data with no peak at the A_1 mass. Note that our sample of events with $|t_{pp}| \leq 1.0$ GeV^2 (Fig. 1a) contains more than five times the number of events in the UR sample and also shows no peak at the mass of the A_1.

Selection by UR of events from the periphery of the 3π Dalitz plot[13] resulted in greatly enhanced production of ($\rho^{\pm}\pi^{\mp}$) final states in the vicinity of the A_1. This was taken to be further evidence for A_1 production, although it was stated that the enhancement might be due in part to a kinematic effect. Figure 2a shows our three-pion mass spectrum for the outer region of the Dalitz plot ($\lambda \leq 0.006$),[13] and Fig. 2b shows those events of Fig. 2a consistent with the decay of at least one charged ρ ($0.67 \leq M(\pi^{\pm}\pi^{0}) \leq 0.86$ GeV). The enhancement at 1.0 GeV is striking and looks very similar to the one obtained by UR. We will now show that this enhancement can be understood as being entirely due to kinematics and therefore no resonance interpretation is necessary.[14] Figure 2c shows a normalized Dalitz plot on which the locations of the contour $\lambda = 0.006$ and the $\rho^{\pm}$ bands for $M(3\pi) = 1.0$ GeV are drawn. As $M(3\pi)$ increases, the $\rho^{\pm}$ bands decrease in width and move across the plot in the directions shown by the arrows. We define the rho probability distribution (RPD) as the fraction of the outer Dalitz plot ($\lambda \leq 0.006$) occupied by the $\rho^{\pm}$ bands [i.e., for $M(3\pi) = 1$ GeV the value of the RPD is the fraction of the outer Dalitz plot in Fig. 2c occupied by the hatched area]. Figure 2d shows the RPD as a function of $M(3\pi)$. A prominent enhancement is seen in the region around 1 GeV. Thus, even a flat three-pion spectrum always appears to have a (ρπ) enhancement in the outer Dalitz plot at about 1 GeV. The result of folding

the RPD into the events in Fig. 2a is shown by the dashed lines in Fig. 2b. The shape of the experimental enhancement is reproduced closely; the absolute normalization is low by only about 15%. It should be kept in mind that the dashed lines are the result of assuming a uniform Dalitz plot population (i.e., no ρ production), and so agreement to within 15% is remarkable.

We now consider the two-pion spectrum as a function of three-pion mass for events with $|t_{pp}| \leq 1$ GeV^2. Following UR, we define regions below, in, and above the A_1 as 840 to 940 MeV, 940 to 1140 MeV, and 1140 to 1240 MeV, respectively. Figures 3a and 3b show the $(\pi^+\pi^-)$ and $(\pi^\pm\pi^0)$ signals for events in Fig. 1a occurring in the lower region. No evidence for the presence of the ρ is seen or expected because of lack of phase space. Figures 3c-f show these distributions for events in and above the A_1 region. The existence of the ρ signal is apparent in the upper control region, and its strength is comparable to that in the A_1 region.[15] The ratio of charged to neutral ρ appears to be the same above the A_1 region as in the A_1 region, making it unnecessary to invoke the presence of the A_1 to explain the data.

Reactions (2a), (2b), and (3)

Evidence for the production of the A_1 in reactions (2a), (2b), and (3) is even weaker than it is in the UR data for reaction (1). UR has 381 examples of reaction (2a), and the 9.0-GeV/c K^+p experiment[4] has 456 events in reaction (2a), 1475 in (2b), and 1141 in (3).

In our experiment, examples of reactions (2b) and (3) were chosen from the four-pronged and V-four-pronged events, respectively, by criteria similar to those used in the study of reaction (1). In addition, for reaction (2b), we required that the missing mass squared be negative when the track fitted as a π^+, and with the greater momentum in the laboratory frame, was interpreted

as a K^+. This removed background produced by the reaction $K^+p \rightarrow K^+p\pi^+\pi^-(n\pi^0)$, for $n > 1$, but did not change the shape of the distribution of interest, namely $M(\pi^+\pi^+\pi^-)$. Reaction (2a) comes from seven-constraint fits to the V-four-pronged events and is unambiguous.

Imposing the requirement that $|t_{pp}| \leq 1.0\ \mathrm{GeV}^2$ leaves us with 1454 examples of reaction (2a), 5431 examples of reaction (2b), and 2647 examples of reaction (3). The relevant three-pion mass spectra are shown in Fig. 4. There is no evidence of A_1 production in these data, especially after we have removed from reaction (3) events where one of the π^+ is consistent with coming from the decay $K^{*+}(890) \rightarrow K^0\pi^+$, a competing reaction (see hatched graphs in Fig. 4).

In summary, we conclude that there is evidence in our experiment against the production of the A_1 in reaction (1) with a cross section greater than 5 μb, and no convincing evidence for its production in the UR data, where a production cross section of 40 μb was quoted. There is also no evidence in our experiment for A_1 production in reactions (2a), (2b), or (3) with a cross section greater than 5 μb.

We thank Joseph J. Murray for his work in beam design and construction. We gratefully acknowledge the assistance of the staff of the Stanford Linear Accelerator and the 82-Inch Bubble Chamber in obtaining the data for this experiment. We also acknowledge the help of the Lawrence Radiation Laboratory Group A Scanning and Measuring Group in data reduction and we are grateful to Gerald R. Lynch for stimulating discussions.

where $\vec{P}_+$ and $\vec{P}_-$ are the three-momenta of the π^+ and the π^-, respectively, in the 3π c.m.) We define this contour using the parameter $\lambda = \left| \frac{\vec{P}_+ \times \vec{P}_-}{Q^2 + 2Qm} \right|^2$, where Q is the total kinetic energy of the three pions in their c.m. and m is the sum of the masses of the three pions. This definition of λ is an energy-invariant generalization of the definition given in Ref. 3. The value of λ used is 0.006.

14. The technique we use is similar to that used in studying the kinematical origin of the H meson. See, for example, A. H. Rosenfeld, N. Barash-Schmidt, A. Barbaro-Galtieri, L. R. Price, P. Söding, C. G. Wohl, M. Roos, and W. J. Willis, Rev. Mod. Phys. 40, 77 (1968); S.-Y. Fung, W. Jackson, R. T. Pu, D. Brown, and G. Gidal Phys. Rev. Letters 21, 47 (1968).

15. Adding the control regions together causes the ρ signal to be obscured. This explains UR's observation of the absence of the ρ signal when they summed their control regions.

Figure Legends

Fig. 1. Three-pion mass spectrum for events in reaction (1) with (a) $|t_{pp}| \leq 1.0$ GeV^2, (b) $|t_{pp}| \leq 0.3$ GeV^2. The dots represent the data of Fig. 1b of Ref. 3 multiplied by 2.6.

Fig. 2. (a) Three-pion mass spectrum for those events of Fig. 1b with $\lambda \leq 0.006$.

(b) Three-pion mass spectrum for those events of Fig. 2a in which at least one $(\pi^{\pm}\pi^{0})$ combination has a mass between 0.67 and 0.86 GeV. The dashed lines are a prediction assuming a completely uniform Dalitz plot (see text).

(c) Normalized Dalitz plot showing the contour $\lambda = 0.006$ and the position of the $\rho^{\pm}$ bands $(0.67 \leq M(\pi^{\pm}\pi^{0}) \leq 0.86$ GeV) for $M(3\pi) = 1$ GeV. The arrows show the directions in which the respective ρ bands move for increasing $M(3\pi)$.

(d) The ρ probability distribution (RPD) -- the fraction of the periphery of the Dalitz plot ($\lambda \leq 0.006$) occupied by the $\rho^{\pm}$ bands as a function of $M(3\pi)$.

Fig. 3. (a), (c), (e) The $(\pi^{+}\pi^{-})$ mass distribution for events of Fig. 1a below (900 events), in (2559 events), and above the A_1 region (1411 events), respectively.

(b), (d), (f) The sum of the $(\pi^{+}\pi^{0})$ and $(\pi^{-}\pi^{0})$ mass distributions for events of Fig. 1a below, in, and above the A_1 region, respectively (2 combinations per event).

Fig. 4. Three pion mass spectra for events with $|t_{pp}| \leq 1.0$ GeV.^{2}

The hatched events are those with a competing $K^{*+}(890)$ removed.

(a) $M(\pi^+\pi^+\pi^-)$ from reaction (2a).

(b) $M(\pi^+\pi^+\pi^-)$ from reaction (3).

(c) $M(\pi^+\pi^-\pi^0)$ from reaction (3), two combinations per event.

(d) $M(\pi^+\pi^+\pi^-)$ from reaction (2b).

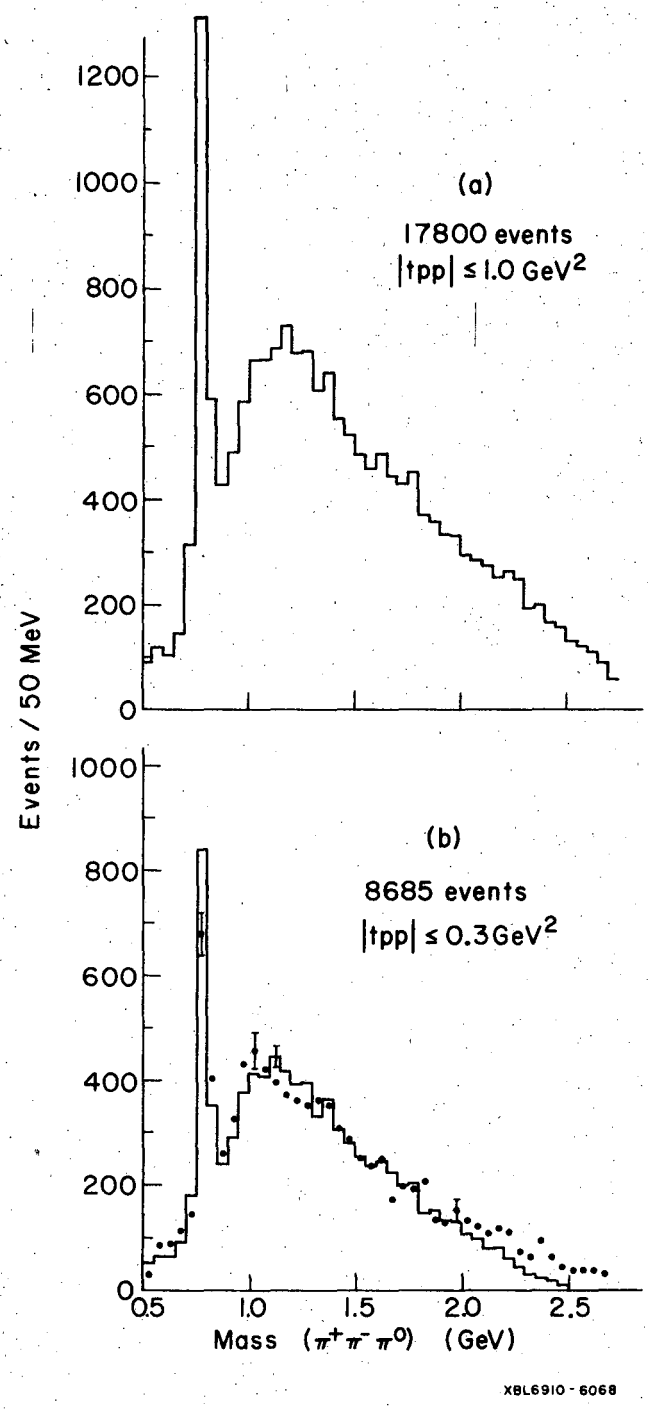
1200
1000
800
600
400
200
0
(a)
17800 events
|tpp| ≤ 1.0 GeV²
Events / 50 MeV
1000
800
600
400
200
0
(b)
8685 events
|tpp| ≤ 0.3GeV²
0.5
1.0
1.5
2.0
2.5
Mass (π⁺π⁻π⁰) (GeV)
XBL6910-6068

Fig. 1

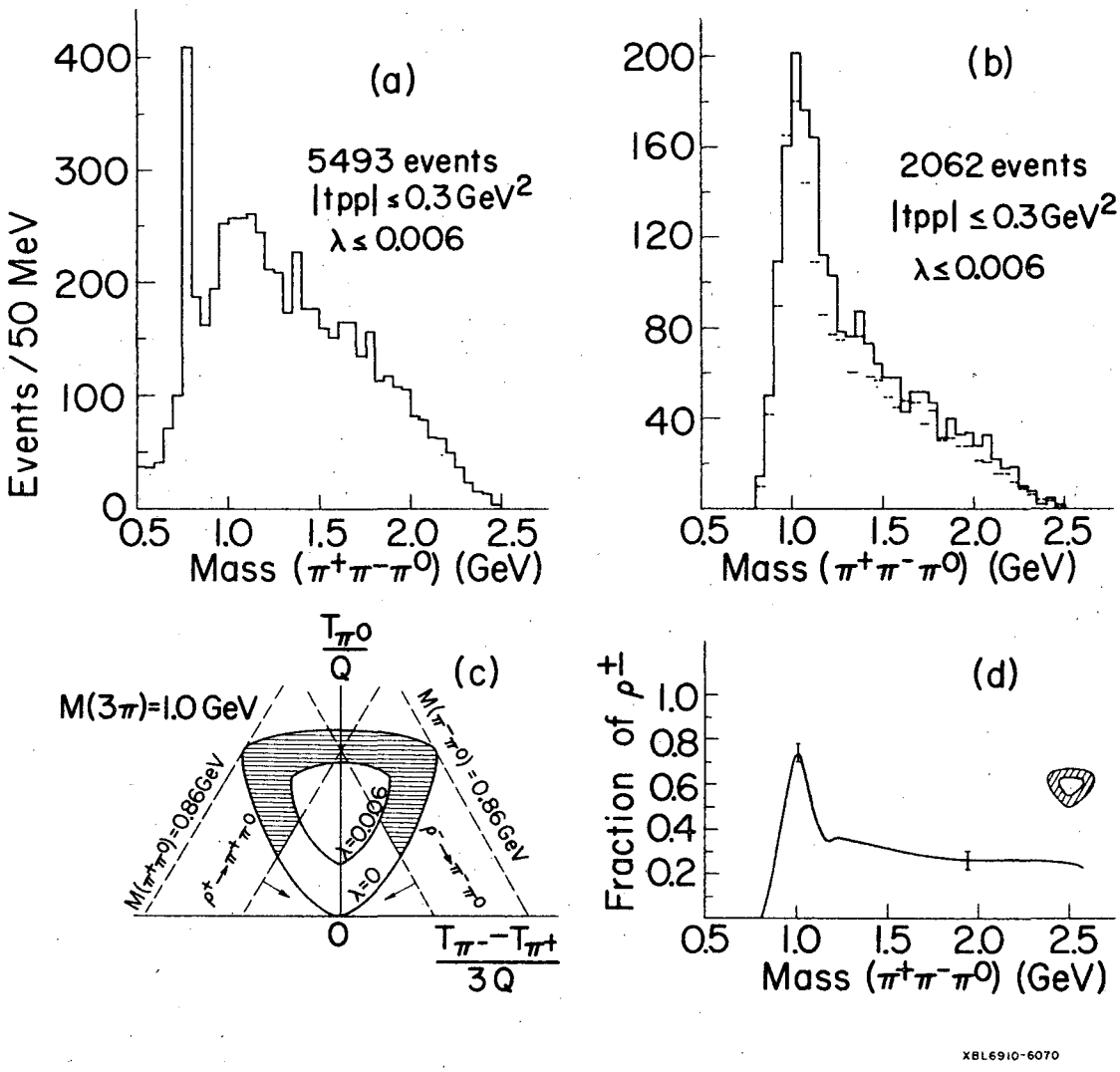
(a)
5493 events
|tpp| ≤ 0.3 GeV²
λ ≤ 0.006
Events / 50 MeV
Mass (π⁺π⁻π⁰) (GeV)
(b)
2062 events
|tpp| ≤ 0.3 GeV²
λ ≤ 0.006
Mass (π⁺π⁻π⁰) (GeV)
(c)
M(3π)=1.0 GeV
M(π⁺π⁰)=0.86GeV
M(π⁻π⁰)=0.86GeV
λ=0.006
λ=0
ρ⁺→π⁺π⁰
ρ⁻→π⁻π⁰
(d)
Fraction of ρ±
Mass (π⁺π⁻π⁰) (GeV)
XBL6910-6070

Fig. 2

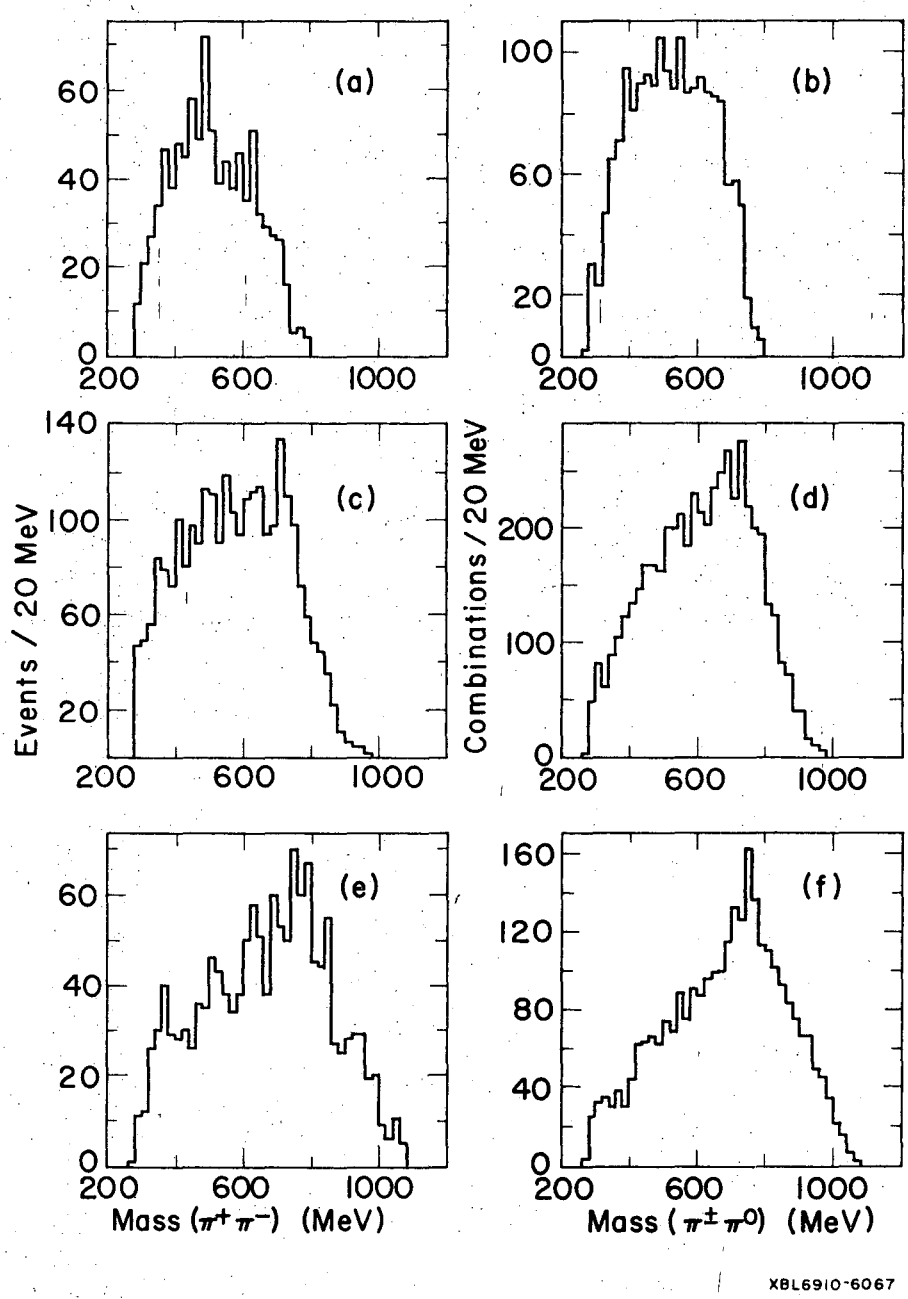
(a)
(b)
(c)
(d)
(e)
(f)
Events / 20 MeV
Combinations / 20 MeV
Mass ($\pi^+\pi^-$) (MeV)
Mass ($\pi^\pm\pi^0$) (MeV)
XBL6910-6067

Fig. 3

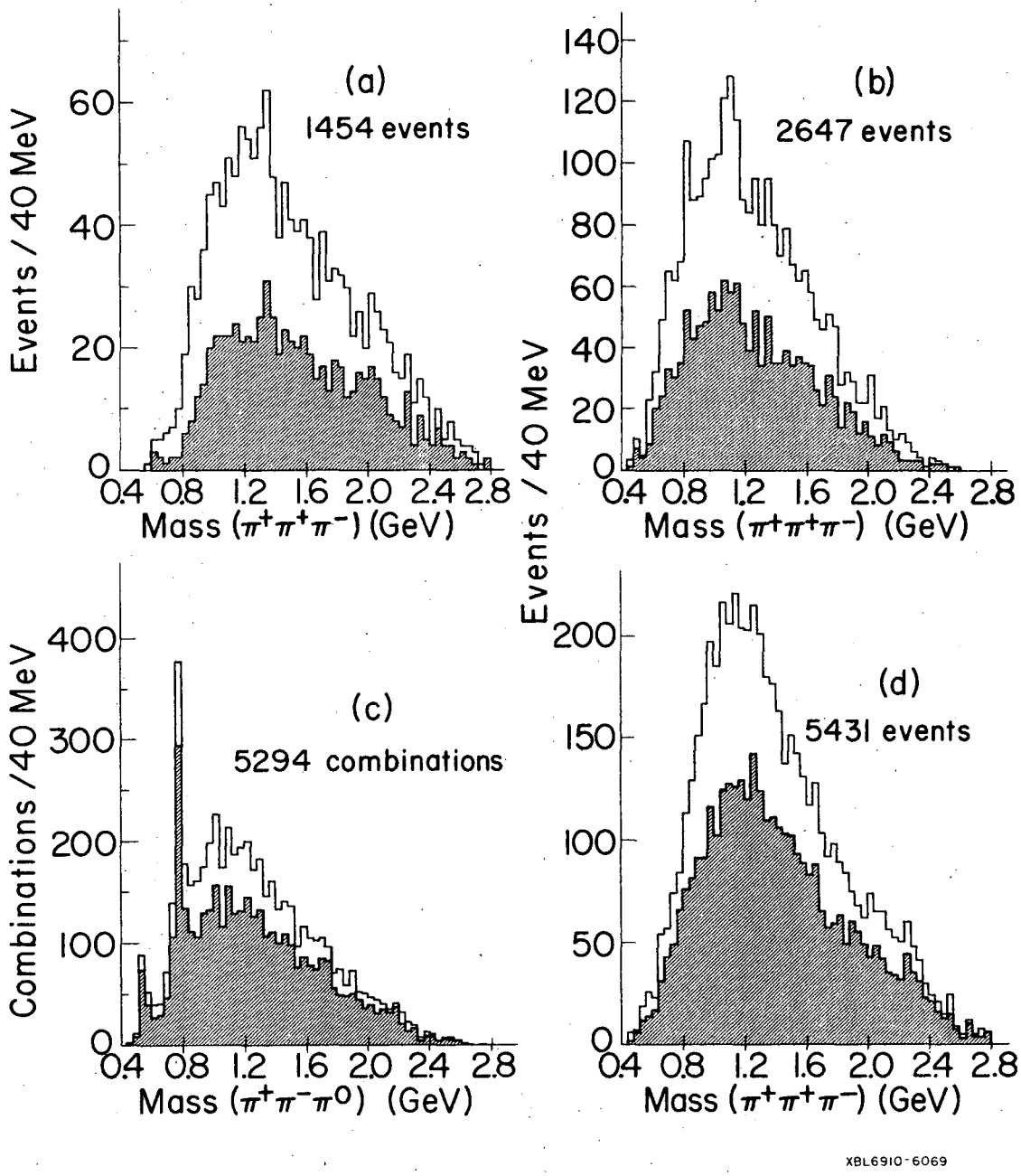
(a)
1454 events
Events / 40 MeV
Mass ($\pi^+\pi^+\pi^-$) (GeV)
(b)
2647 events
Events / 40 MeV
Mass ($\pi^+\pi^+\pi^-$) (GeV)
(c)
5294 combinations
Combinations /40 MeV
Mass ($\pi^+\pi^-\pi^0$) (GeV)
(d)
5431 events
Mass ($\pi^+\pi^+\pi^-$) (GeV)
XBL6910-6069

Fig. 4

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