Title

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Authors

Smith, Gerald A.
Lindsey, James S.
Murray, Joseph J.

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University of California

Ernest O. Lawrence Radiation Laboratory

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PRODUCTION OF $\Xi K(n)\pi$, $\Lambda K\bar{K}(n)\pi$, AND $\Sigma K\bar{K}$ FINAL STATES IN K^-p INTERACTIONS AT 2.45 TO 2.70 GeV/c *

Gerald A. Smith, James S. Lindsey, and Joseph J. Murray
(Presented by Ronald R. Ross)

Lawrence Radiation Laboratory
University of California
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ABSTRACT

The 72-inch hydrogen bubble chamber has been exposed to a separated beam of K^- mesons at incident momenta of 2.45, 2.55, 2.64, and 2.70 GeV/c. Approximately 475 000 pictures with 6 to 7 K^- and 1 to 2 π^- per picture have been taken in the approximate ratio 1:1:3:2 at each of the respective momenta. Scanning and measuring of $\Xi K\pi$, $\Xi K\pi\pi$, $\Lambda K\bar{K}$, $\Lambda K\bar{K}\pi$, and $\Sigma K\bar{K}$ reactions have yielded 518, 85, 426, 26, and 31 events, respectively. These numbers represent approximately two-thirds of the total available data. Production of Ξ^*(1530 MeV), ϕ(1020 MeV), and K^*(890 MeV) is observed in these events over this range of momenta. A detailed discussion of the dominant characteristics of these reactions and the possible existence of new strangeness -2 baryon states of mass less than 2 GeV is presented.

*Work done under the auspices of the U. S. Atomic Energy Commission.

I. INTRODUCTION

In this paper we discuss two topics of recent interest in our continuing analysis of K^--p interactions in the vicinity of 2.5 GeV/c. These topics are (1) interpretation of the ~ 1820-MeV enhancement in the S=-2, B=+1 system and (2) determination of the strong decay modes of the ϕ meson. These analyses have resulted from a study of final states with $\Sigma|S| = 3$ produced from an initial K^--p system. During an extensive exposure of the 72-inch hydrogen bubble chamber to a separated K^- beam at incident momenta of 2.45, 2.55, 2.64, and 2.70 GeV/c, approximately 530 000 pictures have been taken, with six to seven negative kaons and one to two pions per picture. In this paper we confine our discussion to the 2.45-, 2.64-, and 2.70-GeV/c momenta. The reactions of general interest in these analyses are:

(1) $K^-p \to \Xi^- K^{\overset{+}{0}} \pi^{\overset{0}{+}}$

(2) $\Lambda^0 K^0 \bar{K}^0$

(3) $\Lambda^0 K^+ K^-$

(4) $\Sigma^+ K^0 K^-$

(5) $\Sigma^- K^+ \bar{K}^0$

(6) $\Xi^- K^{\overset{0}{+}} \pi^{\overset{0}{-}} \pi^+$

(7) $\Xi^0 K^0 \pi^+ \pi^-$

(8) $\Lambda^0 \bar{K}^0 K^{\overset{0}{+}} \pi^{\overset{0}{-}}$

(9) $\Lambda^0 K^- K^{\overset{0}{+}} \pi^{\overset{+}{0}}$

II. S = -2, B = +1 ENHANCEMENT AT ~1820 MeV

In a recent paper we presented evidence for the existence of a broad S=-2 baryon state with a mass of 1810 MeV.[1] We wish to review its properties and make several qualifying remarks that were not discussed previously. We first consider the three kinematically fitted four-body final states of (6) and (7). We have identified 112 of these types -- 18 at 2.45 GeV/c, 68 at 2.64 GeV/c, and 26 at 2.70 GeV/c. Figure 1a shows a Dalitz plot of $M^2(\Xi^{\bar{0}}\pi^{\pm})$ versus $M^2(\Xi^{\bar{0}}\pi^{\mp})$ for the $\Xi^-K^+\pi^-\pi^+$ and $\Xi^0K^0\pi^+\pi^-$ final states. These two have been grouped together, since each reaction has only one $\Xi\pi$ pair in the $t_z = \pm 1/2$ state. We see that both final states are dominated by the $\Xi^*_{1/2}$(1530 MeV). In Fig. 1b we have plotted $M^2(\Xi^-\pi^+)$ versus $M^2(\Xi^-\pi^0)$ for $\Xi^-K^0\pi^+\pi^0$. In this case, both $\Xi\pi$ systems have $t_z = \pm 1/2$; two orthogonal bands centered at 1530 MeV are evident on this plot. We conclude that the combined three final states involve the production of Ξ^*(1530) in approximately 80% of the cases.

Considering now the possibility of a $\Xi\pi\pi$ interaction, we turn to Fig. 2 where we have constructed Dalitz plots of $M^2(\Xi\pi\pi)$ versus $M^2(K\pi)$ for the three final states under consideration. Fig. 2a contains only those events in which a Ξ^*(1530) is produced; the latter is defined by $2.3 \leq M^2(\Xi^{\bar{0}}\pi^{\mp}) \leq 2.4\ GeV^2$ and $2.3 \leq M^2(\Xi^-\pi^0) \leq 2.5\ GeV^2$. In the case of $\Xi^-K^0\pi^+\pi^0$, the event is accepted if either or both masses satisfy these criteria. The pion common to both axes is that one not included in the Ξ^*(1530). For those events in which only one Ξ^*(1530) is produced, one point is plotted on both the Dalitz plot and the projections. Each event in the Ξ^*(1530) overlap region ($\Xi^-K^0\pi^+\pi^0$ only) is plotted twice on the Dalitz plot and $K\pi$ projection, and once on the $\Xi^*\pi$ projection. Turning our attention to the projection of these events on the $\Xi^*(1530)\pi$ scale, we note an enhancement in the 3.1- to 3.6-GeV^2 region. However, we note also an enhancement in the $K\pi$ distribution in the vicinity of 890 MeV. Since the latter defines a region in which one would expect to observe the $K^*_{1/2}$, this fact could cast some doubt on the validity of a true $\Xi^*\pi$ resonance. Nevertheless, a plot of those events outside the K^* region (unshaded events) still indicates a small enhancement in the vicinity of 3.1 to 3.4 GeV^2. In Fig. 2b we present a Dalitz plot for those events that do <u>not</u> satisfy the $\Xi^*(1530)$ selection criteria. In this case we always plot the $t_z = \pm 1/2$ $K\pi$ combination versus the $\Xi\pi\pi$ combination. We plot two points per event for all $\Xi^- K^0 \pi^+ \pi^0$ events on the Dalitz plot and $K\pi$ projection, and one point on the $\Xi\pi\pi$ projection. Although somewhat limited statistically, the $\Xi\pi\pi$ projection gives some indication of an enhancement in the 3.2 to 3.5 GeV^2 region. If we interpret the enhancements in the $\Xi^*(1530)\pi$ and $\Xi\pi\pi$ projections as a resonance, the best parameters are $E_0 = 1820 \pm 20$ MeV and $\Gamma \sim 80$ MeV.

In Fig. 3 we show the mass distributions of S=-2 pairs from three-body final states (1) through (5). In the vicinity of 1820 MeV an excess of events is observed in all three distributions ($\Xi^-\pi^{+}_{0}$, $\Lambda\bar{K}^{0}_{-}$, and $\Sigma^{\pm}\bar{K}^{\bar{0}}$ respectively). The curves represent our best estimate of the nonresonant background for these events. It appears highly unlikely that the simultaneous observation of enhancements in $\Xi^*\pi$, $\Xi\pi\pi$, $\Xi\pi$, $\Lambda\bar{K}$, and $\Sigma\bar{K}$ could be accidental, although in each case the ratio of resonant events to apparent background is not overwhelmingly large. Plots of $\Lambda\bar{K}\pi$ mass distributions from reactions (8) and (9) do not indicate the presence of the 1820-MeV enhancement (plots not shown). Using only the data at 2.64 and 2.70 GeV/c (total sample minus 18 $\Xi K\pi\pi$ events at 2.45 GeV/c) and including corrections for neutral decay loss, we find that $\Xi^{*0}(1820)$

decays in the following proportions:

$\Xi^*\pi : \Xi\pi\pi : \Xi\pi : \Lambda\bar{K} : \Sigma\bar{K} :: 80 : > 22 : 14 : 64 : 3.$

Considering now possible isospin assignments, we note that observation of a $\Lambda\bar{K}$ decay mode unambiguously determines the isospin to be one-half. In addition, charge independence in the decay of a $\Xi^*(I=1/2 \text{ or } 3/2)$ produced in the reaction $K^- + p \rightarrow \Xi^{*0} + K^0$ and decaying via an intermediate state $\Xi^*(1530)\pi$ predicts the ratio

$$[\Xi^{*0}(1530) \rightarrow \Xi^-\pi^+]\,\pi^0 / [\Xi^{*-}(1530) \rightarrow \Xi^-\pi^0]\,\pi^+$$

(one for $I = 1/2$, four for $I = 3/2$). We find this ratio to be 0.5 ± 0.3 for that sample of events in which only one $\Xi\pi$ combination in $\Xi^- K^0 \pi^+ \pi^0$ is a $\Xi^*(1530)$. At the moment there is no direct evidence for any particular spin or parity assignment for the 1820-MeV state.

In summary, we have observed enhancements in several $S = -2$, $B = +1$ particle systems in the vicinity of 1820 MeV. We interpret these enhancements as manifestations of a resonant state with a mass of 1820 ± 20 MeV and $\Gamma \sim 80$ MeV. The isospin of the state is one-half; no information has been gained on the spin and parity of the state. Total track length scanned at 2.64 and 2.70 GeV/c amounts to $\sim 4.0 \times 10^6$ meters, giving a total corrected cross section of $\sim 15\ \mu b$ for the production of $\Xi^*(1820)$.

III. STRONG DECAY MODES OF THE ϕ MESON

In addition to the aforementioned reactions (2) and (3) which involve the production of $K\bar{K}$ pairs, we have attempted to observe other decay modes of the ϕ meson consistent with the established quantum numbers of this particle, $0\ 1^{--}$. Specifically, the only decay modes above threshold, other than $K\bar{K}$, that one would expect in the strong decay are $\pi^+\pi^-\pi^0$ and $\pi\rho$. To look for these modes, we have studied the reaction $K^- + p \rightarrow \Lambda^0\pi^+\pi^-\pi^0$ at 2.45, 2.64, and 2.70 GeV/c. Figure 4a is a histogram of the effective mass of $K\bar{K}$ pairs from the reactions $K^- + p \rightarrow \Lambda^0 K^+ K^-$ and $\Lambda^0 K^0 \bar{K}^0$, where we have restricted the latter class of events to those in which a lambda and a K_1^0 are observed in the bubble chamber. Normalizations for the two types of events are not the same. The shaded portion of the histogram contains those events with low momentum transfer to the lambda ($\Delta^2_{p,\Lambda} \leq 0.80\ \text{GeV}^2$). Approximately 80% of the events in the ϕ peak (1010 to 1030 MeV) fall into this category. Turning our attention to the question of $\pi^+\pi^-\pi^0$ and $\pi\rho$ decay modes, in Fig. 4b we have plotted the effective mass distribution of the $\pi^+\pi^-\pi^0$ triplet from the $\Lambda^0\pi^+\pi^-\pi^0$ final state. No apparent structure is observed at 1020 MeV. However, when we consider only the low-momentum-transfer events where all charge states of the Y_1^*(1345 to 1435 MeV) have been removed (shaded area), we observe a peak of approximately 20 events over background at 1020 MeV.

To test the hypothesis of a $\pi\rho$ decay mode, in Fig. 4c we have plotted the effective mass of events (with low-momentum-transfer events and Y^*'s removed) which have at least one $\pi\pi$ combination in the interval 700 to 800 MeV, corresponding to the ρ meson. A substantial peak is observed at 1020 MeV. Subtraction of the events of Fig. 4c from the shaded area of 4b gives the distribution which contains no ρ's. It shows no enhancement at 1020 MeV. We conclude therefore that the ϕ decay to $\pi^+\pi^-\pi^0$ is predominantly via the intermediate state $\pi\rho$. From these data we calculate the relative rate $R[(\phi \rightarrow \pi\rho)/(\phi \rightarrow K^+K^-)] = 0.7 \pm 0.3$, where we have used only the low-momentum-transfer data, and have corrected for the phase space omitted by the Y_1^* removal in $\Lambda^0\pi^+\pi^-\pi^0$. It is not now possible to determine the total relative rate $R[(\phi \rightarrow \pi\rho)/(\phi \rightarrow K\bar{K})]$ because of difficulties in establishing the absolute normalization for the $\Lambda^0K^+K^-$ or $\Lambda^0\pi^+\pi^-\pi^0$ samples.

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FIGURE LEGENDS

Fig. 1. (a) Dalitz plot of $M^2(\Xi^{\bar{0}}\pi^{\pm})$ versus $M^2(\Xi^{\bar{0}}\pi^{\mp})$ for the final states (⊖) $\Xi^-K^+\pi^+\pi^-$ and (O) $\Xi^0K^0\pi^+\pi^-$. In the projections, the $\Xi^0K^0\pi^+\pi^-$ events are shaded. (b) Dalitz plot of $M^2(\Xi^-\pi^+)$ versus $M^2(\Xi^-\pi^0)$ for the final state $\Xi^-K^0\pi^+\pi^0$.

Fig. 2. (a) Dalitz plot of $M^2\Xi^*(1530)\pi$ versus $M^2(K\pi)$ for all $\Xi K\pi\pi$ events containing a $\Xi^*(1530)$. Final states are denoted by (◇) $\Xi^-K^+\pi^+\pi^-$, (O) $\Xi^0K^0\pi^+\pi^-$, and (●) $\Xi^-K^0\pi^+\pi^0$. Events in the $\Xi^*(1530)$ overlap region ($\Xi^-K^0\pi^+\pi^0$ only) are plotted twice (□). The solid curve is the best estimate of the nonresonant background for all events, the dashed for those events with the K^* band removed (unshaded). (b) Dalitz plot of $M^2(\Xi\pi\pi)$ versus $M^2(K\pi)$ for all $\Xi K\pi\pi$ events not containing a $\Xi^*(1530)$. Final states are denoted by (◇) $\Xi^-K^+\pi^+\pi^-$, (O) $\Xi^0K^0\pi^+\pi^-$, and (▩) $\Xi^-K^0\pi^+\pi^0$ (2 points per event).

Fig. 3. (a) Mass distribution of $\Xi^-\pi^+$ and $\Xi^-\pi^0$ for the final states $\Xi^-\pi^+K^0$ and $\Xi^-\pi^0K^+$. The $K^*(890)$ events have been subtracted. (b) Mass distribution of $\Lambda^0K + \Lambda^0\bar{K} + \Lambda^0K^-$ for the final states $\Lambda^0K^0\bar{K}^0$ and $\Lambda^0K^+K^-$. Since the K^0 and $\bar{K}^0$ are indistinguishable, two points are plotted for each $\Lambda^0K\bar{K}^0$ event. The $\phi(1020)$ events have been subtracted. (c) Mass distribution of $\Sigma^-\bar{K}^0$ and Σ^+K^- for the final states $\Sigma^-\bar{K}^0K^+$ and $\Sigma^+K^-K^0$. The data in all plots are at 2.64 and 2.70 GeV/c. Curves in (a) and (b) are our best estimate of the nonresonant background.

Fig. 4. (a) Mass distribution of $K^0\bar{K}^0$ (events with visible Λ^0 and K_1^0) and K^+K^- pairs from the reaction $K^-p \to \Lambda^0K\bar{K}$. (b) Mass distribution of $\pi^+\pi^-\pi^0$ triplets from the reaction $K^-p \to \Lambda^0\pi^+\pi^-\pi^0$. (c) Mass distribution of $\pi^+\pi^-\pi^0$ triplets, where at least one $\pi\pi$ pair is in the 700-to 800-MeV interval. The shaded events have been selected for low momentum transfer ($\Delta^2_{p,\Lambda} \leq 0.80$ GeV^2) to the lambda, with $Y_1^*(1385)$ having been removed in (b) and (c).

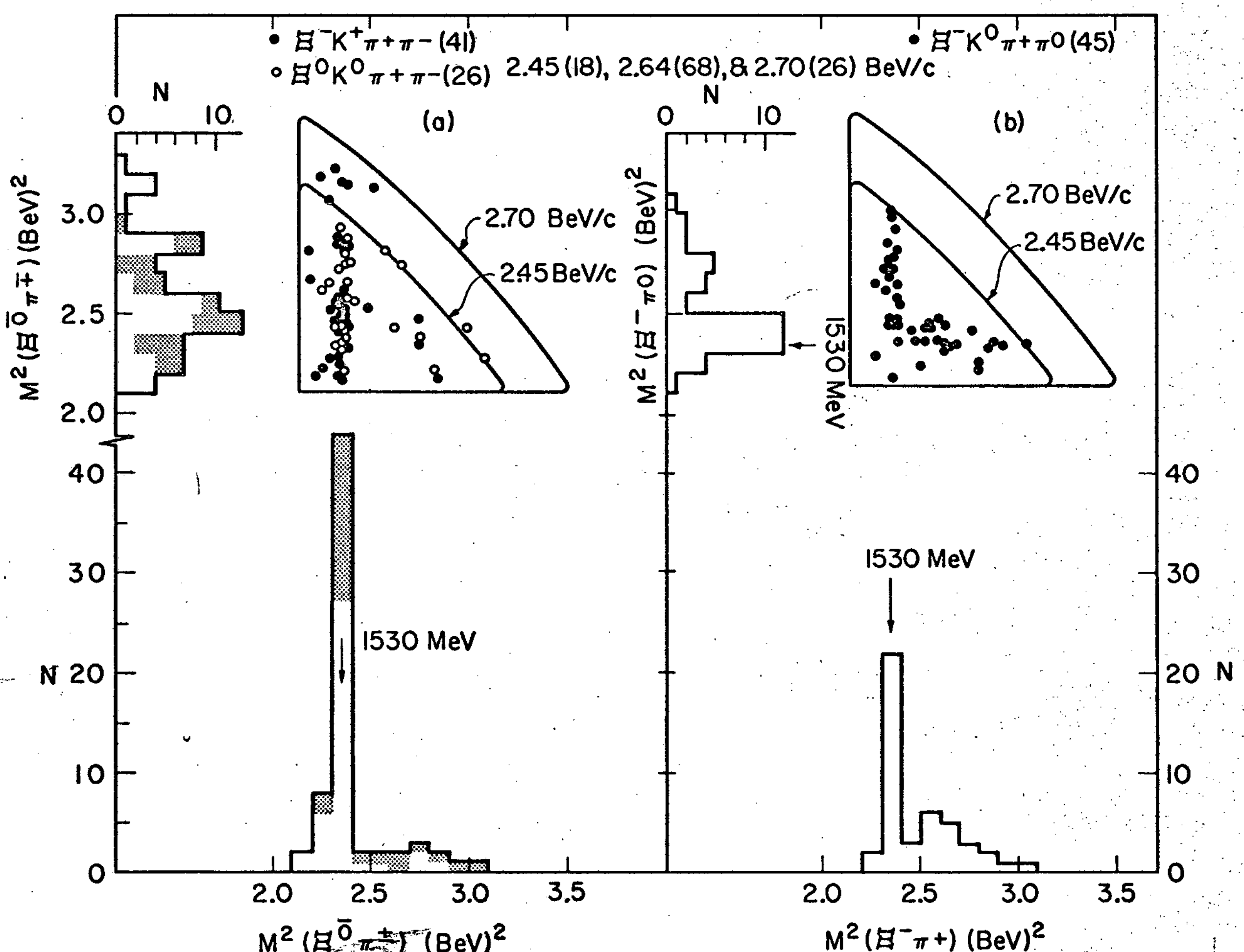

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Fig. 1

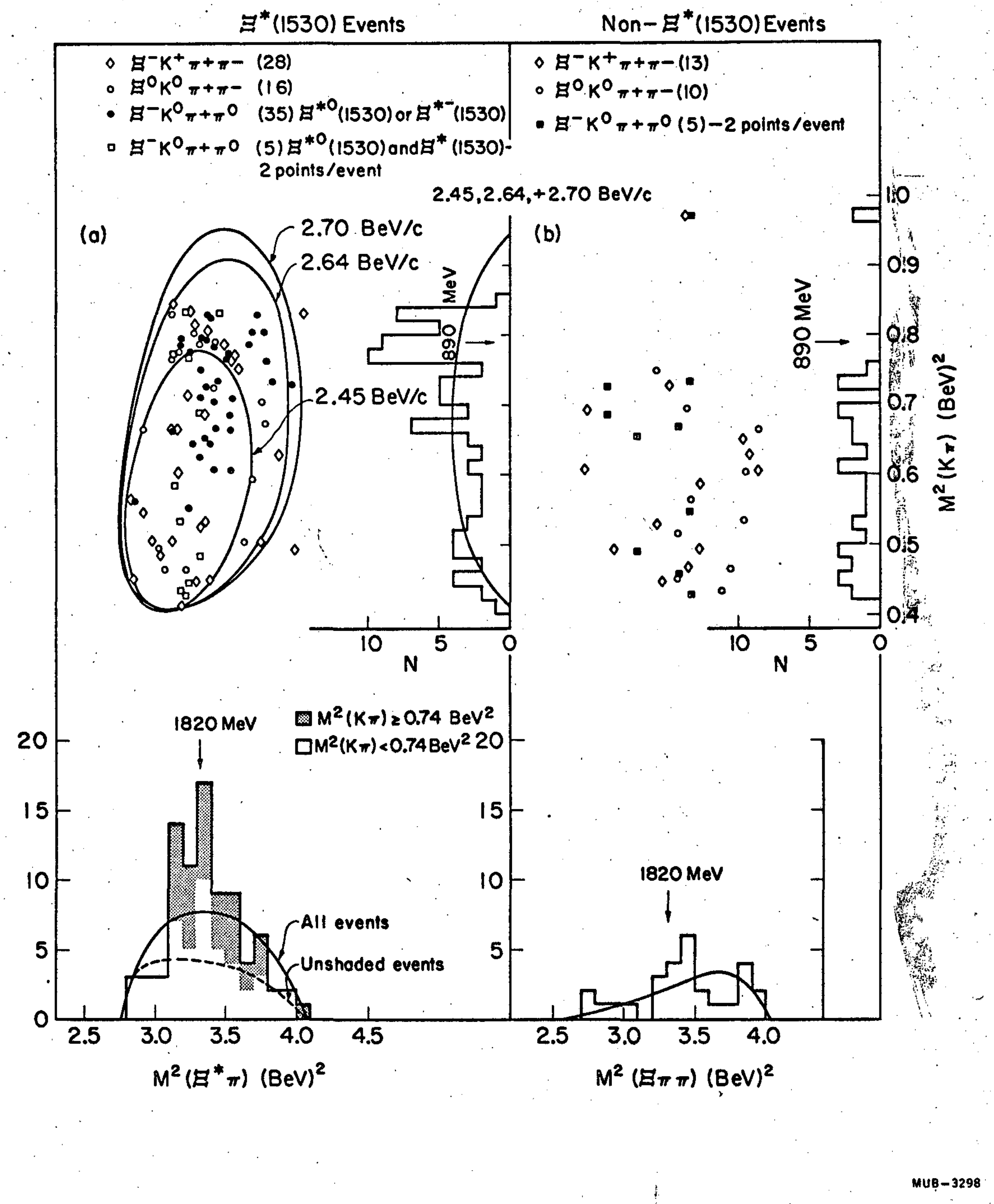
Ξ*(1530) Events
Non-Ξ*(1530) Events
◇ Ξ⁻K⁺π⁺π⁻ (28)
○ Ξ⁰K⁰π⁺π⁻ (16)
● Ξ⁻K⁰π⁺π⁰ (35) Ξ*⁰(1530) or Ξ*⁻(1530)
□ Ξ⁻K⁰π⁺π⁰ (5) Ξ*⁰(1530) and Ξ*(1530)- 2 points/event
◇ Ξ⁻K⁺π⁺π⁻ (13)
○ Ξ⁰K⁰π⁺π⁻ (10)
■ Ξ⁻K⁰π⁺π⁰ (5)—2 points/event
2.45, 2.64, +2.70 BeV/c
(a)
(b)
2.70 BeV/c
2.64 BeV/c
2.45 BeV/c
890 MeV
N
M²(Kπ) (BeV)²
1820 MeV
M²(Kπ) ≥ 0.74 BeV²
M²(Kπ) < 0.74 BeV²
All events
Unshaded events
M²(Ξ*π) (BeV)²
M²(Ξππ) (BeV)²
MUB-3298

Fig. 2

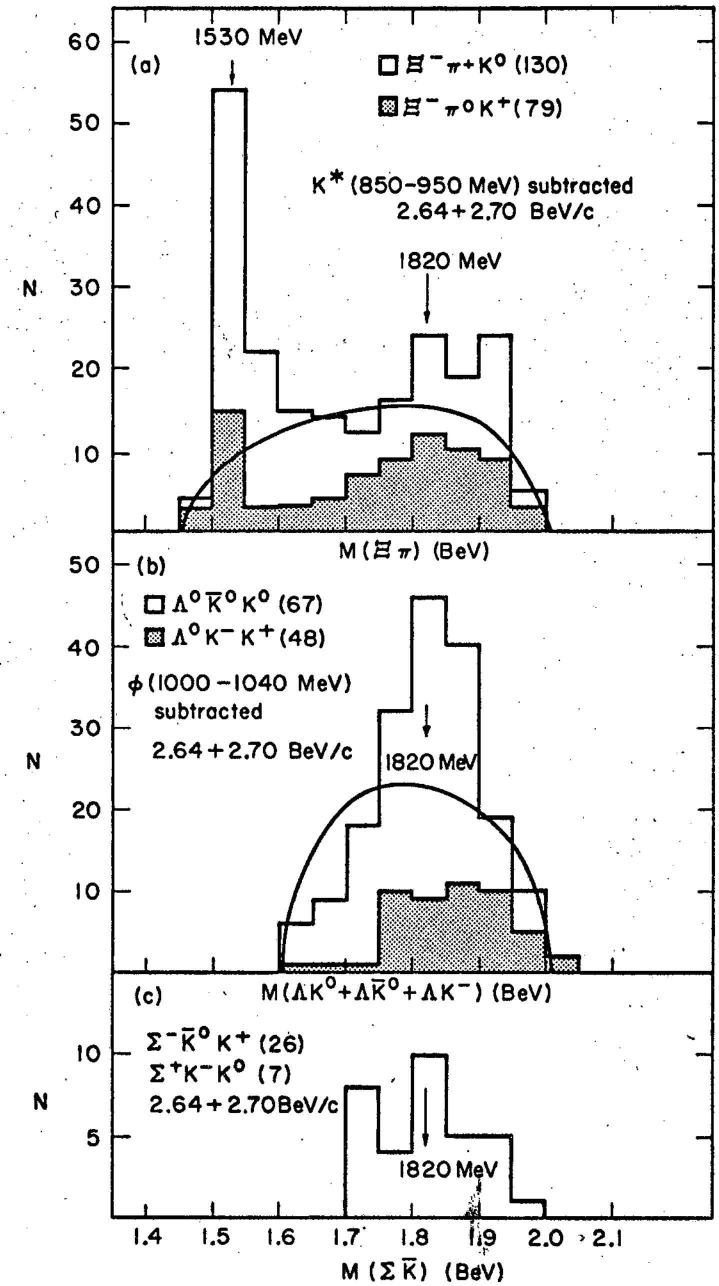
1530 MeV
(a)
Ξ⁻π+K⁰ (130)
Ξ⁻π⁰K⁺ (79)
K* (850-950 MeV) subtracted
2.64+2.70 BeV/c
1820 MeV
N
M (Ξπ) (BeV)
(b)
Λ⁰K̄⁰K⁰ (67)
Λ⁰K⁻K⁺ (48)
φ (1000-1040 MeV)
subtracted
2.64+2.70 BeV/c
1820 MeV
M (ΛK⁰+ΛK̄⁰+ΛK⁻) (BeV)
(c)
Σ⁻K̄⁰K⁺ (26)
Σ⁺K⁻K⁰ (7)
2.64+2.70BeV/c
1820 MeV
M (ΣK̄) (BeV)
MUB-3295

Fig. 3

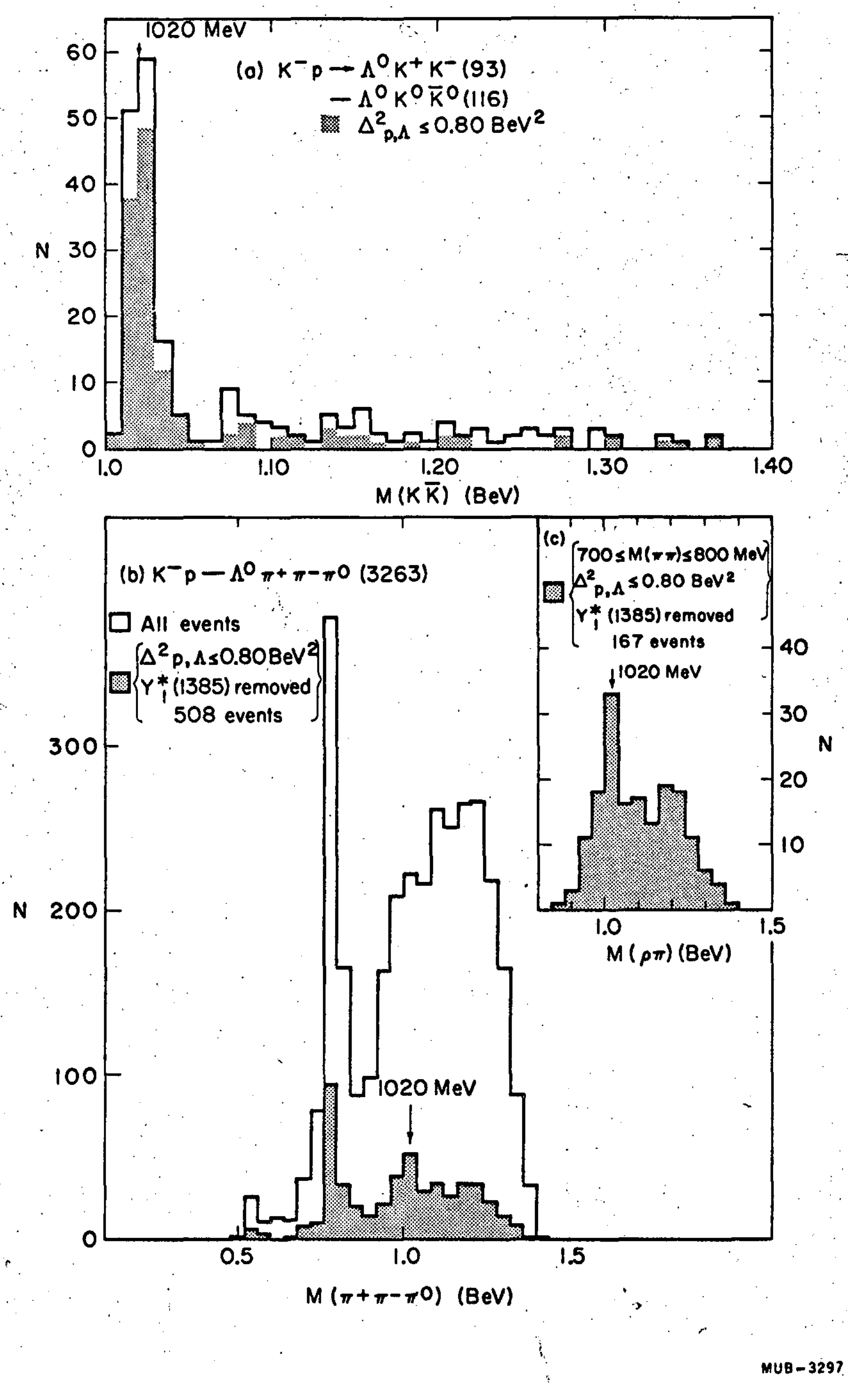
1020 MeV
(a) K⁻p → Λ⁰K⁺K⁻ (93)
— Λ⁰K⁰K̄⁰ (116)
Δ²p,Λ ≤ 0.80 BeV²
N
M (KK̄) (BeV)
(b) K⁻p — Λ⁰π⁺π⁻π⁰ (3263)
All events
Δ²p,Λ ≤ 0.80 BeV²
Y*₁ (1385) removed
508 events
1020 MeV
N
M (π⁺π⁻π⁰) (BeV)
(c)
700 ≤ M(ππ) ≤ 800 MeV
Δ²p,Λ ≤ 0.80 BeV²
Y*₁ (1385) removed
167 events
1020 MeV
N
M (ρπ) (BeV)
MUB-3297

Fig. 4