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Ernest O. Lawrence Radiation Laboratory

FINAL-STATE INTERACTION INVOLVING HYPERONS

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Among the general group of baryon resonances, the $S = -1$ and -2 states have been the subject of a great deal of experimental scrutiny in the past few years. Much information about these states has been gained, particularly from the analysis of bubble-chamber pictures of incident K^- and π^- beams. In this paper we restrict our discussion to the group of <u>$S = -2$ states</u> (generally called Ξ^*) so that we may relate in detail some relatively recent experimental observations regarding these states.

We have recently exposed the 72-inch hydrogen bubble chamber to a K^- beam of various momenta in the range 2.1 to 2.7 BeV/c.[1] The data reported here result from analysis of approximately 700 000 pictures of this exposure with an average of 7 to 8 K^- per picture. We have systematically analysed all reactions involving $B = +1$, $S = -2$ particle groups. In summary, with regard to resonance production, (a) we observe copious production of $\Xi^*(1532)$ and $K^*(890)$; (b) we have observed a new resonance of mass 1817 ± 7 MeV which is coupled strongly to the $\Lambda\bar{K}$ channel, and our results for the $\Xi\pi$ system in this mass region appear to be consistent with the recent suggestion by the Paris-Saclay-Amsterdam collaboration group of a resonance near 1933 MeV; (c) there now appears to be evidence for a resonance with mass 1705 MeV coupled to both the $\Lambda\bar{K}$ and $\Xi\pi$ channels; (d) our results support those of previous experiments in the absence of the predicted resonance in the 1600-MeV region.

We present our data in Figs. 1 through 6. The $\Xi\pi$ and $K\pi$ mass distributions for the reactions $K^- + p \to \Xi^- \pi^0 K^+$, $\Xi^- \pi^+ K^0$, and $\Xi^0 \pi^- K^+$ are shown in Figs. 1 through 3 respectively. In Fig. 4 we plot the $\Lambda^0 \overline{K}$ mass distributions for the reactions $K^- + p \to \Lambda^0 K^0 \overline{K}^0$ and $\Lambda^0 K^+ K^-$, where events that fall in the $\phi^0(1020)$ band have been removed. Since the K^0 and $\overline{K}^0$ are indistinguishable, we have included both $\Lambda^0 K^0$ and $\Lambda^0 \overline{K}^0$ mass values in all plots involving the $\Lambda^0 K^0 \overline{K}^0$ final state. The data are plotted separately at incident momenta (BeV/c) of (a, e) 2.1, (b, f) 2.45 and 2.55 combined, (c, g) 2.63 and 2.70 combined, and (d, h) all momenta combined. In Fig. 5 we have combined data from the previous four figures in a way such that resonance production in the $S = -2$ system is most apparent. The dashed curves are calculated phase space not including any final-state interactions. Shaded events are those that are also in the $K^*(890)$ region (830 to 950 MeV). Figure 6 is constructed for the express purpose of looking for possible electromagnetic decays of the type $\Xi^* \to \Xi^- + \gamma$. A discussion of these data follows.

$\Xi^*(1532)$ and $K^*(890)$ Production

In all $\Xi\pi$ and $K\pi$ charge states at all momenta studied we observe copious production of these established resonances. Inasmuch as the properties of these states are well determined ($I = 1/2$, $J^P = 3/2^+$ for Ξ^*, 1^- for K^*), we defer any more discussion to later and more detailed analyses.

$\Xi^*(1817)$ Production

In recent papers by Smith et al.[2,3] (Berkeley) and Badier et al.[4,5] (Paris-Saclay-Amsterdam) the existence of $\Xi^*(1817)$ was established. The state is observed to decay into $\Lambda^0 \overline{K}$, as shown in Fig. 4, (c) and (g) at incident momenta of 2.63 to 2.70 BeV/c. The enhancement in $\Lambda^0 K^-$ establishes the $S = -2$ assignment. Badier et al. observe the same effect in $\Lambda^0 K^0 \overline{K}^0$ at 3 BeV/c, although they do not see an enhancement in $\Lambda^0 K^-$. The discrepancy may be statistical, since the Paris-Saclay-Amsterdam report contains only 30% as many $\Lambda^0 K^+ K^-$ events (non-ϕ only) as the Berkeley data of Fig. 4 (g). The $\Lambda^0 \overline{K}$ decay mode establishes an isospin assignment of one-half. The previously quoted value of the width of the state (≈ 60 MeV) was overestimated by the Berkeley group; we now arrive at a value of $\Gamma \approx 30 \pm 7$ MeV, not in violent disagreement with the Paris-Saclay-Amsterdam value of 12 ± 4 MeV.

Referring to the $\Xi\pi$ mass distributions at 2.63 to 2.70 BeV/c in Figs. 1(c), 2(c), and 3(c), we observe broad enhancements in all three distributions in the mass range ≈ 1825 to 1950 MeV. The combined data are shown in Fig. 5(a). The Berkeley group originally interpreted this enhancement as an alternate decay mode of the 1817-MeV resonance. At that time the $\Xi^0 \pi^-$ data were not available, and the upward shift of the central value of the peak from 1817 MeV plus the broadening of the peak was attributed to statistical effects or possible interference with the crossing $K^*(890)$ band. However, with the added statistics these possibilities now seem unlikely. A far more appealing resolution of this inconsistency with the $\Lambda^0 \overline{K}$ data is provided by the recent work of the Paris-Saclay-Amsterdam group. Their data at 3 BeV/c suggest the presence of an $I = 1/2$ resonance with mass $\approx 1933 \pm 16$ MeV and full width $\approx 140 \pm 35$ MeV. If this is the case, then at 2.63 to 2.70 BeV/c the Berkeley data would show the presence of the resonance severely attenuated by phase space above ≈ 1925 MeV. A rough fit to the data of Fig. 5(a) with a

Breit-Wigner resonance form with $E_0 = 1933$, $\Gamma = 140$ MeV plus phase space indicates that the shape of the distribution in this region is consistent with such a model. Therefore, we conclude that the 1817-MeV resonance is strongly coupled to the $\Lambda^0\bar{K}$ channel, whereas the $\Xi\pi$ enhancement may be entirely due to the presence of a new resonance at ≈ 1933 MeV.[6]

Evidence for a $\Xi\pi$, $\Lambda\bar{K}$ Resonance at 1705 MeV

In Figs. 1(d) and 5(b) enhancements in the vicinity of 1700 MeV are observed for the $\Xi^-\pi^0$ and combined $\Lambda\bar{K}^0$ (K^0), ΛK^- systems, respectively. We have combined these plots in Fig. 5(c) to optimize the effect statistically. Although the normalization of the phase-space curve may be subject to some alteration, we estimate the probability that the enhancement is a statistical fluctuation to be less than 1/300. The $\Xi^-\pi^0$ and ΛK^- modes identify the strangeness to be -2, whereas the $\Lambda\bar{K}$ mode proves the isospin one-half assignment. Presently the cross-section normalization for the $\Xi^0\pi^-$ sample is unknown, thus we are unable now to make reliable consistency checks on this isospin assignment. The apparent width of the enhancement is approximately 15 to 20 MeV.

Search for a Resonance near 1600 MeV

A unitary octet consisting of the $N_{1/2}^*(1512)$, $Y_0^*(1520)$, and $Y_1^*(1660)$ leads to a prediction for the Ξ^* member at a mass of 1598 MeV. The calculation of Glashow and Rosenfeld[7] yields a predicted width of ≈ 0.6 MeV. A number of experimenters have failed to observe this state. In the data of Figs. 1 through 4 no significant enhancements appear around 1600 MeV. However, the small predicted width of the state suggests that perhaps it may decay electromagnetically in the form $\Xi^* \to \Xi + \gamma$. To investigate this possibility we have selected all events that fit the hypotheses Ξ^-K^+,

$\Xi^- K^+ \pi^0$, or $\Xi^- K^+$ + (two or more neutral pions). Normally any event of the type $\Xi^- K^+ \gamma$ would fall into one of these categories if fitted to the same. For these events we have calculated from measured quantities the square of the missing mass recoiling against the $\Xi^- K^+$ system. In Fig. 6 we have plotted this quantity versus the square of the invariant mass of the (Ξ^- + missing mass) combination. Any interaction involving the Ξ^- and a massless particle would show up as a cluster located on the M^2 (neutrals) = 0 line. We observe significant structure at M^2 (neutrals) ≈ 0 and M^2 (Ξ^- + neutrals) ≈ 1.75 (1320 MeV), corresponding to the $\Xi^- K^+$ final state, and at M^2 (neutrals) ≈ 0.02 and M^2 (Ξ^- + neutrals) ≈ 2.35 (1532 MeV), corresponding to the Ξ^{0*}(1532) K^+ final state. In particular, there is no evidence for any structure near M^2 (neutrals) ≈ 0 and M^2 (Ξ^- + neutrals) ≈ 2.56 (1600 MeV). We conclude that, if the Ξ^0(1600) does exist, it is being produced at a rate equal to less than $\lesssim$ 0.02 times that for Ξ^*(1532).

We wish to acknowledge the diligent efforts of our scanners and measurers, plus the usual excellent operation of the 72-inch bubble chamber by the crew under the direction of Mr. Robert Watt. We thank Professor Luis Alvarez for his continuing support.

REFERENCES AND FOOTNOTES

* This work was done under the auspices of the U. S. Atomic Energy Commission.

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6. Analysis of the $\Xi K\pi\pi$ final state by the Berkeley group (see Ref. 3) gives a two-standard-deviation enhancement at 1817 MeV for $\Xi\pi\pi$. However, the intensity of this effect is only $\approx 25\%$ that of $\Lambda^0\overline{K}$. The work of the Paris-Saclay-Amsterdam group agrees with this result.

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FIGURE LEGENDS

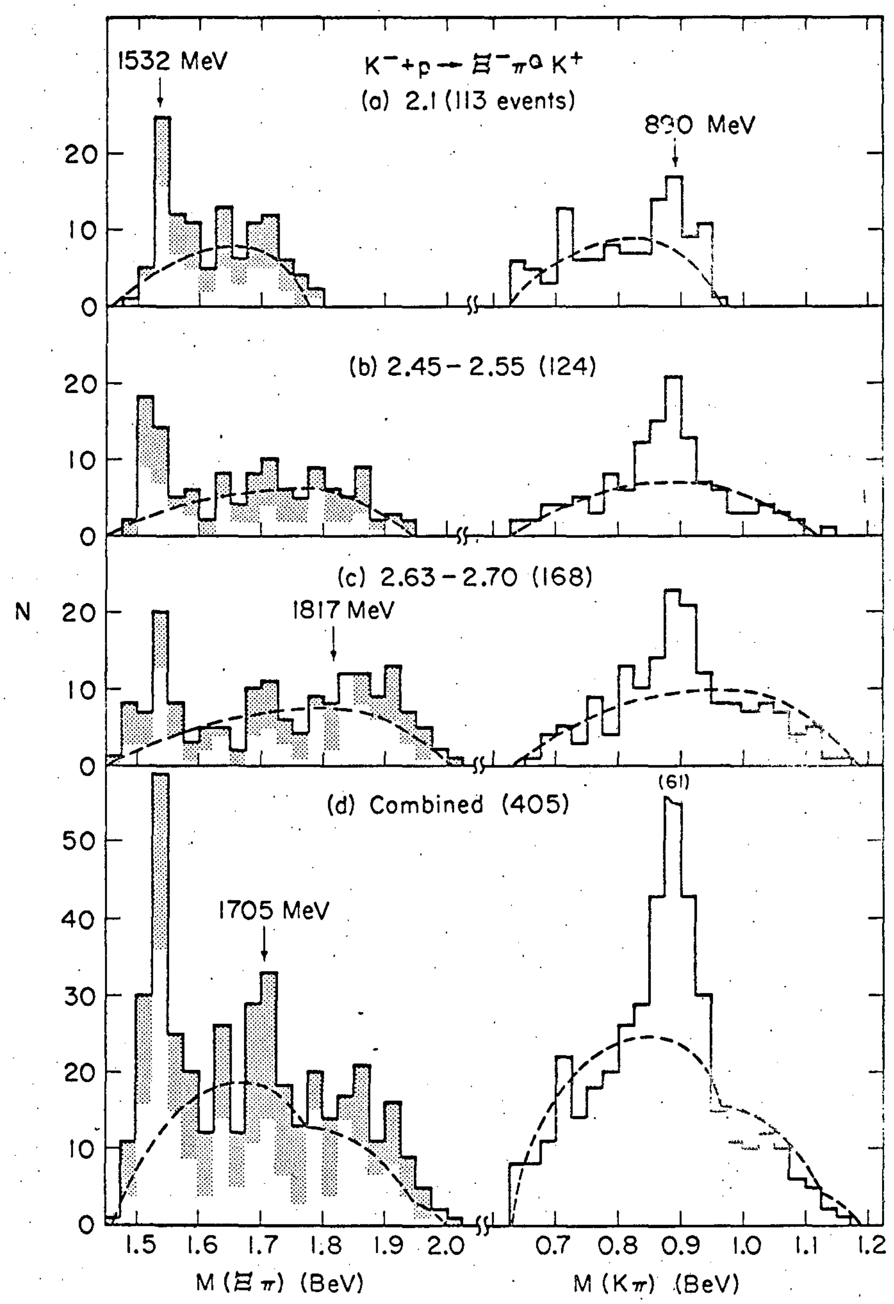
Figs. 1 to 3. $\Xi\pi$ and $K\pi$ mass distributions for the respective final states $\Xi^-\pi^0K^+$, $\Xi^-\pi^+K^0$, and $\Xi^0\pi^-K^+$ at (a) 2.1 BeV/c, (b) 2.45 and 2.55 BeV/c combined, (c) 2.63 and 2.70 BeV/c combined, and (d) all momenta combined. Shaded events are in the $K^*(890)$ band, defined by $830 \leq M(K\pi) \leq 950$ MeV. The dashed curves are calculated phase space without any final-state interactions.

Fig. 4. (a) —(d) Combined ΛK^0 and $\Lambda\overline{K}^0$ mass distributions for the final states $\Lambda^0K^0\overline{K}^0$ at 2.1 BeV/c, 2.45 and 2.55 BeV/c combined, 2.63 and 2.70 BeV/c combined, and all momenta combined, respectively. Events in the band $1000 \leq M(K\overline{K}) \leq 1040$ have been removed.

(e) – (h) ΛK^- mass distributions for the final state $\Lambda^0K^+K^-$ at 2.1 BeV/c, 2.45 and 2.55 BeV/c combined, 2.63 and 2.70 BeV/c combined, and all momenta combined, respectively. Events in the band $1000 \leq M(K\overline{K}) \leq 1040$ have been removed. The dashed phase-space curves do not include any final-state interactions.

Fig. 5(a). $\Xi\pi$ mass distribution for $\Xi^-\pi^0K^+$, $\Xi^-\pi^+K^0$, and $\Xi^0\pi^-K^+$ combined at 2.63 to 2.70 BeV/c only. (b) Combined ΛK^0, $\Lambda\overline{K}^0$, and ΛK^- mass distributions at all momenta with events in the band $1000 \leq M(K\overline{K}) \leq 1040$ MeV removed. (c) Combined $\Xi^-\pi^0$, ΛK^0, $\Lambda\overline{K}^0$, and ΛK^- mass distributions at all momenta with events in the band $1000 \leq M(K\overline{K}) \leq 1040$ MeV removed.

Fig. 6. Missing mass squared (calculated from measured variables) versus invariant mass squared of the [Ξ^- + missing mass] combination for all events that fit the hypotheses Ξ^-K^+, $\Xi^-K^+\pi^0$, or Ξ^-K^+ + (two or more missing neutral pions).



MUB-6455

Fig. 1.

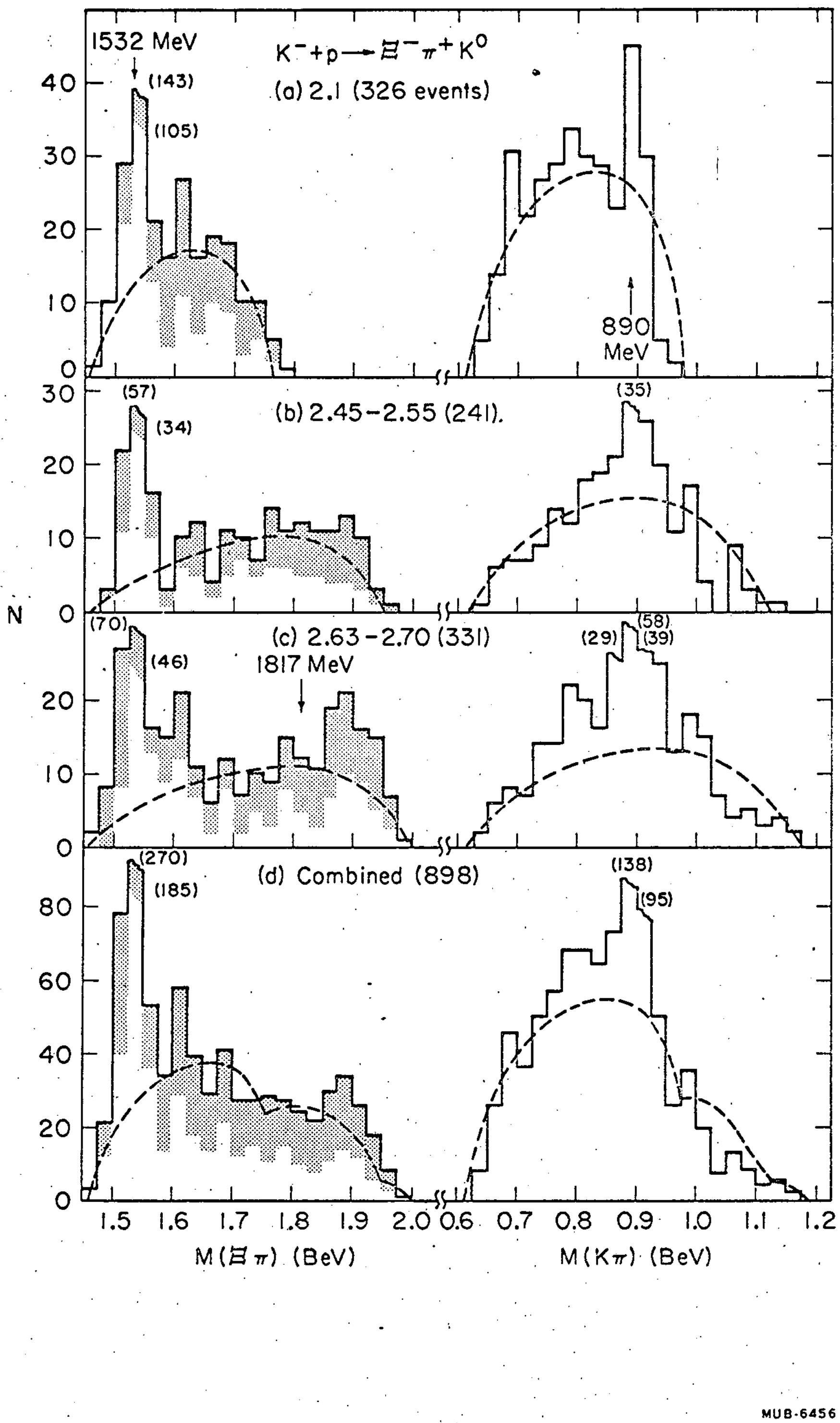
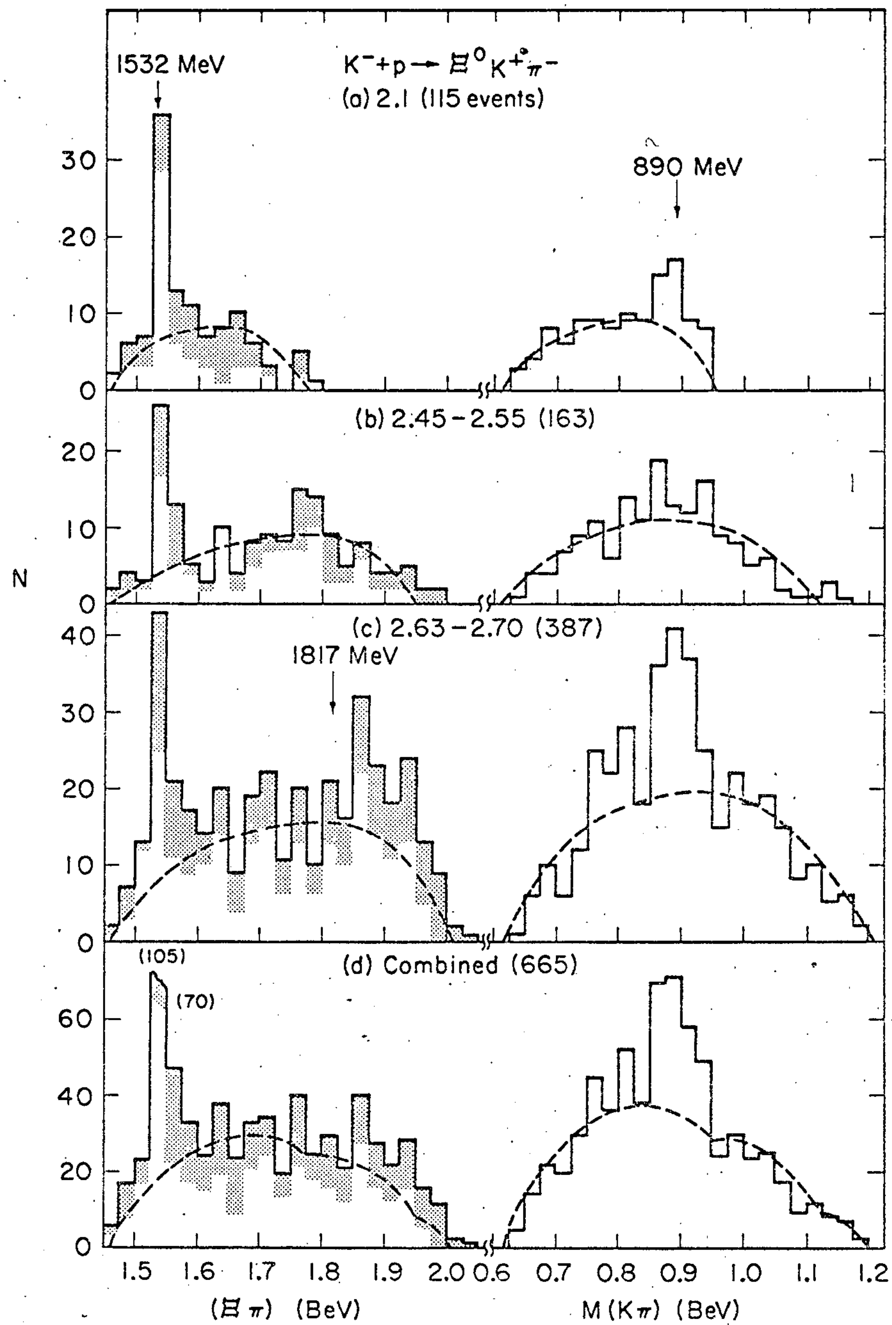

1532 MeV
(143)
(105)
K⁻+p → Ξ⁻π⁺K⁰
(a) 2.1 (326 events)
890 MeV
(57)
(34)
(b) 2.45–2.55 (241)
(35)
N
(70)
(46)
(c) 2.63–2.70 (331)
1817 MeV
(29)
(58)
(39)
(270)
(185)
(d) Combined (898)
(138)
(95)
1.5 1.6 1.7 1.8 1.9 2.0 0.6 0.7 0.8 0.9 1.0 1.1 1.2
M(Ξπ) (BeV)
M(Kπ) (BeV)
MUB-6456

Fig. 2.



MUB-6457

Fig. 3.

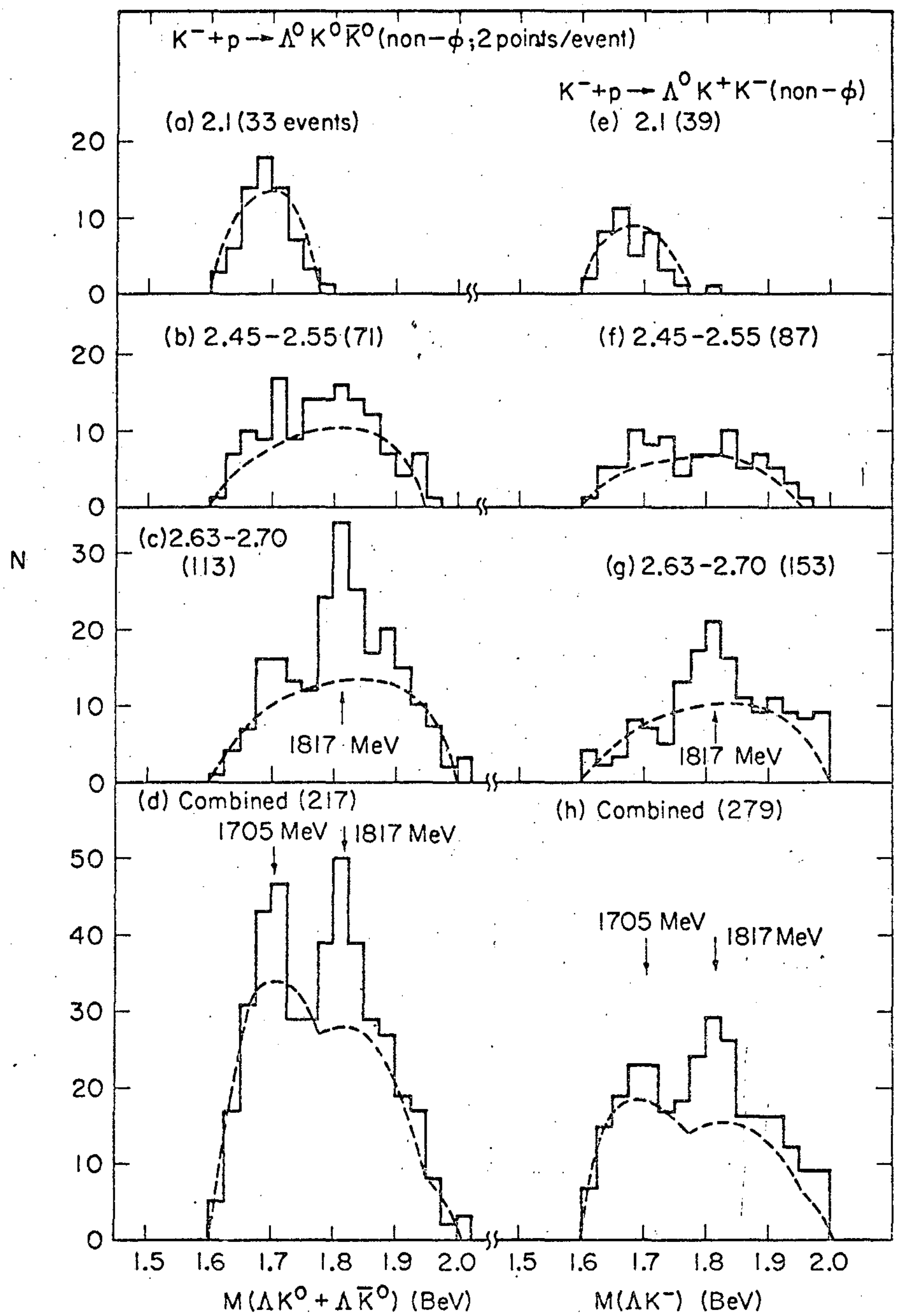

$K^- + p \to \Lambda^0 K^0 \bar{K}^0$ (non-ϕ; 2 points/event)
$K^- + p \to \Lambda^0 K^+ K^-$ (non-ϕ)
(a) 2.1 (33 events)
(e) 2.1 (39)
(b) 2.45-2.55 (71)
(f) 2.45-2.55 (87)
(c) 2.63-2.70 (113)
(g) 2.63-2.70 (153)
1817 MeV
(d) Combined (217)
(h) Combined (279)
1705 MeV
N
$M(\Lambda K^0 + \Lambda \bar{K}^0)$ (BeV)
$M(\Lambda K^-)$ (BeV)
MUB-6458

Fig. 4.

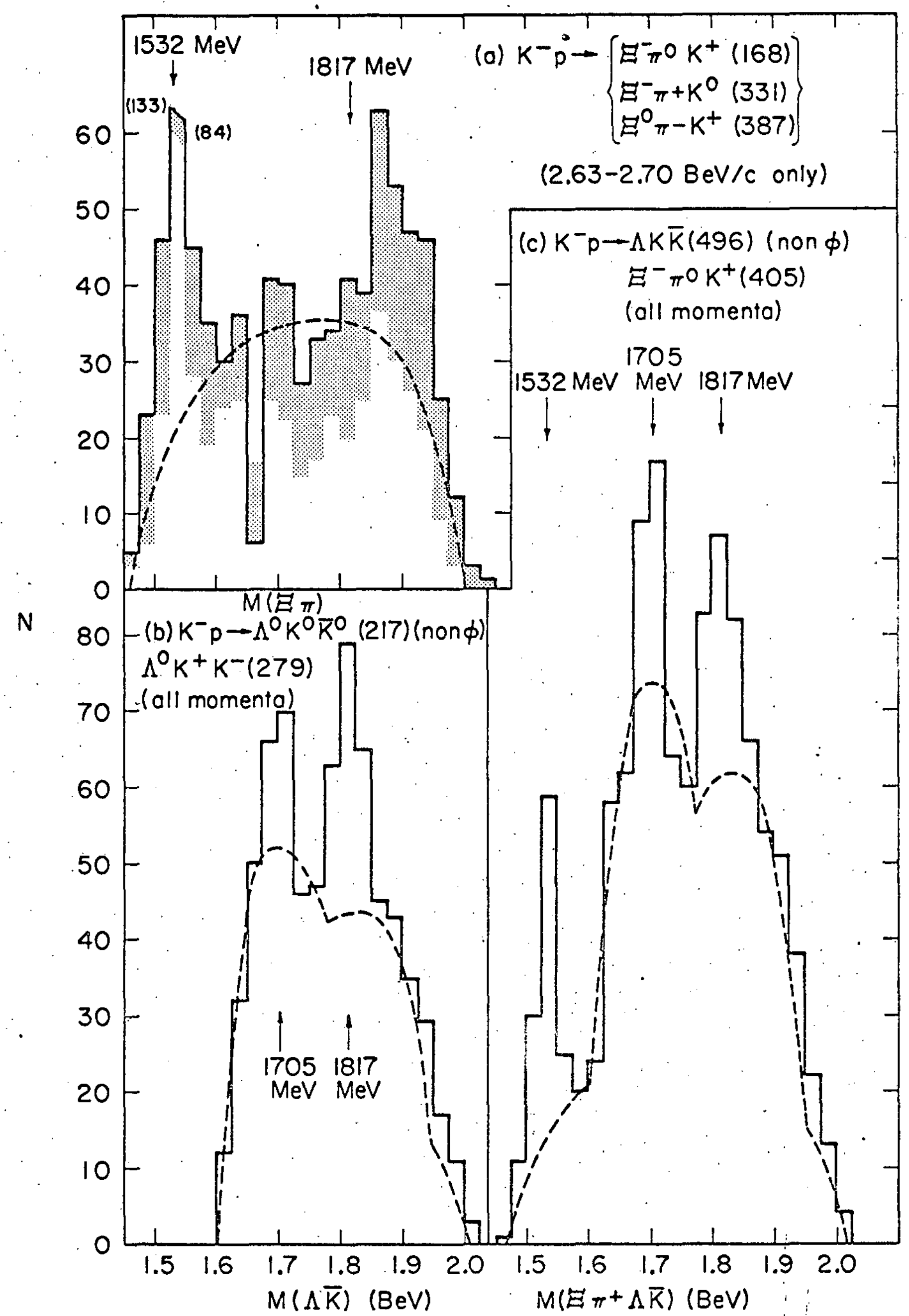

1532 MeV
1817 MeV
(133)
(84)
(a) K⁻p → {Ξ⁻π⁰K⁺ (168), Ξ⁻π⁺K⁰ (331), Ξ⁰π⁻K⁺ (387)}
(2.63-2.70 BeV/c only)
M(Ξπ)
(c) K⁻p → ΛKK̄(496) (non φ)
Ξ⁻π⁰K⁺(405)
(all momenta)
1532 MeV
1705 MeV
1817 MeV
N
(b) K⁻p → Λ⁰K⁰K̄⁰ (217)(non φ)
Λ⁰K⁺K⁻(279)
(all momenta)
1705 MeV
1817 MeV
M(ΛK̄) (BeV)
M(Ξπ+ΛK̄) (BeV)
MUB-6459

Fig. 5.

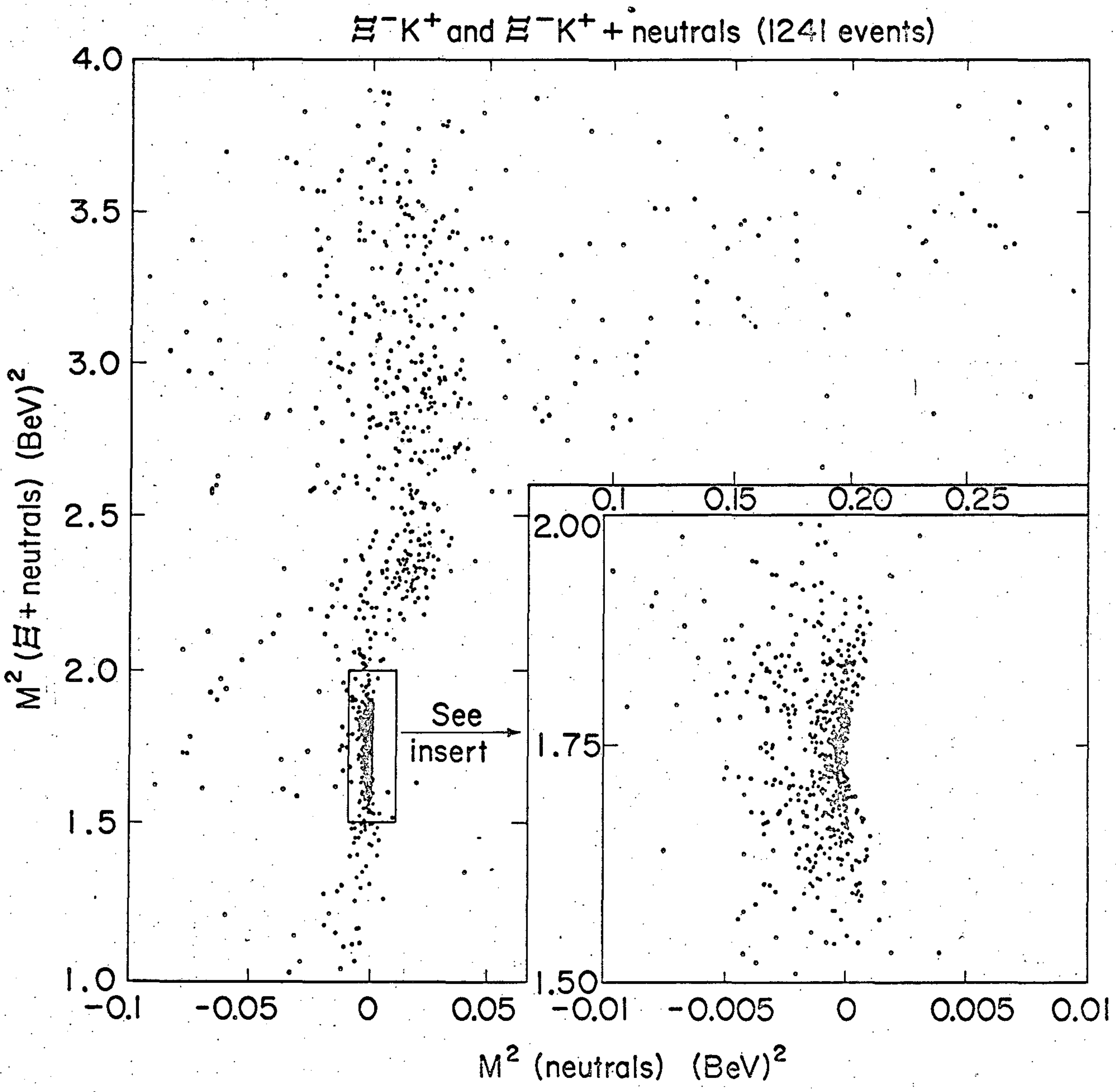

Ξ⁻K⁺ and Ξ⁻K⁺ + neutrals (1241 events)
M² (Ξ + neutrals) (BeV)²
4.0
3.5
3.0
2.5
2.0
1.5
1.0
-0.1
-0.05
0
0.05
See insert
0.1
0.15
0.20
0.25
2.00
1.75
1.50
-0.01
-0.005
0
0.005
0.01
M² (neutrals) (BeV)²
MUB-6460

Fig. 6.