SLAC – PUB – 4132
DPNU – 87 – 16
March 1987
T/E

OBSERVATION OF Ω^{*-} PRODUCTION IN K^-p INTERACTIONS AT 11 GeV/c*

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ABSTRACT

Clear evidence is presented for the production of an Ω^{*-} resonance of mass 2253 ± 13 and width 81 ± 38 MeV/c^2 in K^-p interactions at 11 GeV/c. The state is observed in the $\Xi^*(1530)\overline{K}$ decay mode, and the corresponding inclusive cross section is estimated to be 630 ± 180 nb. Comparisons are made with theoretical predictions and with similar states observed in hyperon beam induced data.

Submitted to *1987 International Europhysics Conference on HEP, Uppsala, Sweden.*

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* Work supported in part by the Department of Energy under contract No. DE-AC03-76SF00515; the National Science Foundation under grant Nos. PHY82-09144, PHY85-13808, and the Japan U.S. Cooperative Research Project on High Energy Physics.

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Although the Ω^- was discovered in 1962, claims for the observation of Ω^{*-} resonances have been made only recently [1, 2]. This situation exists in part because K^-p inclusive cross sections even for production of Ω^- in the 3.5 to 16 GeV/c K^- momentum range covered by most bubble chamber searches are less than 5 μb. Furthermore, counter experiments having both the required sensitivity and the capability of reconstructing the complicated topologies associated with these particles have been performed only within the last few years. Preliminary evidence for an Ω^{*-} with a mass of 2265 MeV/c^2 was reported [1] in the present experiment, using a sample resulting from approximately one half the recorded data. Subsequently, evidence for states with masses of 2251 and 2384 MeV/c^2 observed in Ξ^- induced reactions has been published [2]. In this paper, the full data sample is used to provide clear evidence for the production of an Ω^{*-} state near 2250 MeV/c^2 in the inclusive reaction:

$$
\begin{array}{lllll}
K^-p \rightarrow & \Omega^{*-} + \text{anything} & & & \\
& \hookrightarrow \Xi^{*0}(1530)K^- & & & \\
& & \hookrightarrow \Xi^-\pi^+ & & \\
& & & \hookrightarrow \Lambda\pi^- & \\
& & & & \hookrightarrow p\pi^-
\end{array}
\qquad (1)
$$

The data derive from a 4.1 event/nb exposure of the LASS spectrometer [3] to an 11 GeV/c K$^-$ beam. A total of 1.13×10^8 K^- induced event triggers were accumulated, from which a subsample of 814 events having both a Ξ^- and an identified K^- were extracted for presentation here.

The LASS spectrometer, the beam and the trigger are described in detail in ref. 3.

The experimental arrangement is illustrated in fig. 1. The superconducting solenoidal magnet produced a field of 22.4 kG and was instrumented with proportional wire chambers (PWC's). These were used both for momentum measurement of charged tracks emerging from the liquid hydrogen target, and for triggering. More precise measurement of high momentum, low angle charged tracks was accomplished by means of a dipole spectrometer located downstream of the solenoid. A very loose trigger requiring, in addition to an incoming K^-, at least two outgoing charged tracks was used so that the triggering efficiency for the complex topologies of interest here was essentially 100%.

Particle identification devices included a time-of-flight scintillation counter hodoscope and a threshold Čerenkov counter ($\check{C}_1$) with a pion threshold at 2.6 GeV/c covering the downstream end of the solenoid. A second threshold Čerenkov counter ($\check{C}_2$) with pion threshold at 2.8 GeV/c was located behind the dipole spectrometer. In addition, dE/dx information from the cylindrical PWC's surrounding the target allowed for identification of steeply recoiling protons with momenta below 600 MeV/c. In the present analysis, K^- identification was accomplished using the Čerenkov counters, while information from the other devices contributed mostly to background rejection.

After track reconstruction, a sample of events consistent with the $\Xi^- \rightarrow \Lambda\pi^-$ decay topology was identified. A p and π^- track pair were required to meet with separation less than 8 mm and to yield an effective mass within 8 MeV/c^2 of the nominal Λ mass. The Λ momentum vector was required to point back to within 5 mm of a π^- candidate track and to be such that the $\Lambda\pi^-$ effective mass lay within 22 MeV/c^2 of the Ξ^- mass. This Ξ^- was, in turn, required to swim back to within 1 cm of a primary vertex whose position was determined by a fit to the incoming beam and the primary charged track candidates. Particle identification was used to reject events inconsistent with a Ξ^- interpretation and events with identified protons at the primary vertex. Misidentified γ's were removed from the remaining Λ sample by eliminating events with Λ decay helicity cosine greater than 0.98. Finally, only events with a Ξ^- track length greater than 3 cm were retained. The resulting $\Lambda\pi^-$ effective mass distribution showed a strong Ξ^- signal; events in the mass range 1310 to 1332 MeV/c^2, which contains approximately 10% background, were selected for further study.

The remaining events were tested for existence of a K^-. Clearly, a negative track produced in K^-p induced Ξ^- reactions is more likely to be a π^- than a K^-, since the latter requires production of an additional unit of strangeness. Clear identification of the K^- was therefore necessary, and to this end negative tracks entering the geometrically efficient regions of $\check{C}_1$ or $\check{C}_2$ at momenta above 2.9 GeV/c were required to give no light. To reduce background from poorly measured π^- below threshold, K^- candidates were also required to have momenta at least two standard deviations above threshold.

Evidence that the K^- identification procedure was effective is illustrated in fig. 2. The K^+K^- effective mass distribution in fig. 2(a), from combinations within the selected sample, exhibits a clear ϕ signal. Similarly, a clear $S = -1$ $\overline{K^{*0}}(890)$ signal is present in the $K^-\pi^+$ effective mass distribution of fig. 2(b). Even though both of these states are commonly seen in K^-p interactions in general, they are very rare in Ξ^- final states, since this requires production of additional strange quarks. Indeed, no previous evidence for associated production of Ξ^- and ϕ has been reported in the literature. Distributions corresponding to figs. 2(a) and (b) without K^- identification show no ϕ or $\overline{K^{*0}}$ signals at all. Events in the ϕ region were removed since such K^- candidates were inconsistent with an Ω^{*-} interpretation.

The remaining sample contained 814 events, and yielded 1,259 $\Xi^- K^- \pi^+$ mass combinations whose distribution is shown in fig. 2(c). No structure is obvious for this $S = -3$ baryon system. However, the mass distribution for the $\Xi^- \pi^+$ subsystem [fig. 2(d)] shows a strong Ξ^{*0} (1530) signal. Selecting events in the Ξ^{*0} (1530) mass range ($1510 < M_{\Xi^-\pi^+} < 1555$ MeV/c^2) results in the $\Xi^- K^- \pi^+$ mass histogram of fig 3(a). A clear signal at a mass of approximately 2250 MeV/c^2 is apparent, which is interpreted to correspond to the decay of an Ω^{*-} to Ξ^{*0} (1530)K^- . Also shown as solid dots in fig. 3(a) is the distribution for events in the Ξ^{*0} (1530) sidebands ($M_{\Xi^-\pi^+} < 1510$ or $1555 < M_{\Xi^-\pi^+} < 1600$ MeV/c^2) normalized to the estimated number of background events under the Ξ^{*0} (1530) signal. No peak is observed near 2250 MeV/c^2, indicating that the observed structure is associated purely with Ξ^{*0} (1530).

In order to investigate the possibility that the K^- were actually π^- which were misidentified as a result of Čerenkov inefficiency, events were selected exactly as above, except that the "K^- " tracks were required to give light in either $\check{C}_1$ or $\check{C}_2$. All momentum requirements were as before, and the tracks were still assigned a K^- mass. The Ξ^{*0} (1530) "K^- " mass distribution that resulted [fig. 3(b)], in contrast to the true K^- distribution, showed no structure suggestive of a peak in the 2250 MeV/c^2 region. This demonstrated that the peak was not due to misidentified pions, and also that it was not a kinematic effect due to the acceptance limitations placed on the negative track by the Čerenkov identification requirement. Weighting each of these "K^-" events by $(1-\epsilon)/\epsilon$ (where ϵ is the π^- Čerenkov efficiency) provided an estimate of the mass distribution corresponding to misidentified π^-'s. This distribution, indicated by open dots in fig. 3(a), showed that such punch-through contributes negligibly to the signal.

The significance of the Ω^{*-} signal may be estimated from the data of fig 3(a). The Ξ^{*0} sideband distribution (black dots) represents the non-Ξ^{*0} background under the peak in the histogram. The difference between these two distributions (fig. 4) represents the Ξ^{*0} (1530)K^- spectrum. The solid curve of fig. 4(a) is the result of a fit to the data using the expression

$$\frac{dN}{dM} = q\left[\frac{c_1}{\left(M_0^2 - M^2\right)^2 + M_0^2\Gamma^2} + c_2 + c_3 M\right]$$

$$\text{with} \quad \Gamma = \Gamma_0\left(\frac{q}{M}\right)\left(\frac{M_0}{q_0}\right) \quad ;$$

M_0 and Γ_0 are the Ω^{*-} mass and width respectively; q (q_0) is the K^- momentum in the rest frame of a $\Xi^* K^-$ system of mass $M(M_0)$, and the c_i are parameters to be fit. The fit, which has a χ^2 of 8.5 for 9 degrees of freedom (d.o.f.), yields Ω^{*-} parameter values

$$M_0 = 2253 \pm 13 \quad \text{MeV/c}^2$$

$$\Gamma_0 = \quad 77 \pm 35 \quad \text{MeV/c}^2$$

and a corresponding signal of 41.2 ± 10.2 events. The dotted curve represents the non-resonant background, and agrees well in magnitude and shape with the corresponding π^- punch-through distribution.

In order to test the sensitivity of these results to the assumption of a linear background, a second fit has been carried out which makes use of two incoherent Breit-

Wigner distributions. The results are shown in fig. 4(b), and the corresponding Ω^{*-} parameter values are

$$M_0 = 2253 \pm 13 \quad \mathrm{MeV/c^2}$$
$$\Gamma_0 = \quad 85 \pm 40 \quad \mathrm{MeV/c^2} \quad .$$

The χ^2 is 4.9 for 8 d.o.f., and the signal is estimated to contain 47.5 ± 11.6 events. Averaging the results of these two fits, the Ω^{*-} parameter values are

$$M_0 = 2253 \pm 13 \quad \mathrm{MeV/c^2}$$
$$\Gamma_0 = \quad 81 \pm 38 \quad \mathrm{MeV/c^2} \quad ;$$

the corresponding signal is estimated to contain 44 ± 11 events, and so has 4 σ significance. The mass scale uncertainty is less than 1 MeV/c^2, and Monte Carlo studies indicate that the effective mass resolution in the vicinity of the Ω^{*-} signal is $\sim$ 12 MeV/c^2.

The second Breit-Wigner of fig. 4(b) corresponds to

$$M_0 = 2561 \pm 50 \quad \mathrm{MeV/c^2}$$
$$\Gamma_0 = \quad 124 \pm 94 \quad \mathrm{MeV/c^2}$$

but the signal contains only 23.7 ± 11.3 events, and so is of only $\sim 2\ \sigma$ significance.

The acceptance for Ω^{*-} events in LASS is dominated by the K^- particle identification requirements. The geometric reconstruction and trigger efficiencies are quite uniform, and rather insensitive to the details of the recoil system. In order to study these effects, a sample of Monte Carlo events was generated. The Ω^{*-}, having the mass and width obtained in the fit above, was produced with an $e^{1.5u'}$ (where u' is the 4-momentum transfer above minimum from K^- to Ω^{*-}) distribution similar to the data, and was allowed to decay isotropically. The recoil system was assumed to be a $K^+K^+\pi^-$ system with a phase space decay, and was generated with an effective mass distribution whose shape agreed with that observed for the data sample. Track coordinates were created for each charged track; the Monte Carlo events were then processed through the complete chain of analysis programs, and a sample was chosen precisely as indicated above for the real data. The resulting acceptance in u' proved to be quite uniform. However, the K^- identification criteria resulted in an efficiency which showed a strong forward peak in the decay helicity angle, θ, between the K^- in the Ω^{*-} rest system and the Ω^{*-} in the laboratory; in fact events in the backward hemisphere ($\cos\theta < 0$) were totally excluded. This, together with the requirement that the K^- be above Čerenkov threshold, resulted in an overall acceptance estimate of 7.4%.

Correcting for acceptance losses in this way, the inclusive cross section for Ω^{*-} production multiplied by its branching ratio to $\Xi^*(1530)\overline{K}$ was estimated to be 630 ± 180 nb, corrected for all unseen decay modes. For comparison, the inclusive cross section for Ω^-, summed over all decay modes, is 3.9 ± 0.6 μb at this momentum [4].

To study Ω^{*-} production characteristics, the events corresponding to the region of Ξ^{*0} K^- mass below 2.43 GeV/c^2 in fig. 4 were selected to represent a rather clean Ω^{*-} sample; events from the $\Xi^*(1530)$ side-band regions were included in this sample, but were given negative weight. The distribution in u' for these events was described well, after acceptance correction, by the form $d\sigma/du' = Ae^{Bu'}$ with $B = 1.5\pm0.3(\mathrm{GeV/c})^{-2}$. The $S = +2$ meson system recoiling against the Ω^{*-} exhibited a mass distribution which was strongly peaked near the high mass limit of 2.3 GeV/c^2, with most events in the vicinity of 2 GeV/c^2; this indicates a central production mechanism. The average charge multiplicity of this recoil system was found to be 1.9 ± 0.8.

The distribution of $\cos\theta$ could, in principle, be used to shed light on the spin-parity of the Ω^{*-} . Unfortunately, the strong dependence of acceptance upon this angle, together with the low statistics, made it impossible to rule out an isotropic distribution, so that no spin-parity information could be inferred.

Several predictions exist for Ω^{*-} states. Richard [5] calculates masses for baryons using a hyperspherical formalism with two-body $q-q$ forces described by a potential of the form $V(r) = A + Br^{\alpha}$. Using values for A, B and α derived from meson spectroscopy, and including spin forces, he predicts three positive parity states between 2274 and 2358 MeV/c^2. Isgur and Karl [6] have proposed a model for baryons with a $q-q$ potential incorporating a confinement term (though not the same as that observed from meson data); hyperfine structure is computed on the basis of colored gluon exchange, and symmetry breaking resulting from the difference in quark masses. This model has been applied by Chao, Isgur and Karl [7], using parameters obtained from N, Δ, Σ, and Λ baryon data, to predict the Ω^- spectrum. In addition to the Ω^- (1672), the model predicts two states $(1/2^-, 3/2^-)$ at 2020 MeV/c^2, a state with $J^P = 3/2^+$ at 2065 MeV/c^2, five states of positive parity, and spins 1/2 to 7/2 between 2190 and 2210 MeV/c^2, and two states $(3/2^+, 5/2^+)$ at 2265 MeV/c^2. It follows that the existence of an Ω^{*-} resonance of mass 2253 MeV/c^2 is quite consistent with theoretical predictions.

In view of the similarity in mass and width, it is tempting to identify the Ω^{*-} reported here with the state reported in ref. [2] with $M = 2251 \pm 12$, $\Gamma = 48 \pm 20$

MeV/c^2. This was seen in the inclusive $\Xi^- K^- \pi^+$ system produced by 116 GeV/c Ξ^- interactions in beryllium. However, the Ω^{*-} observed in the present experiment appears to decay purely to $\Xi^* \overline{K}$. In contrast, the authors of ref. [2] claim, in addition, substantial decay of their state via the three body mode. In the absence of spin-parity information, it follows that the question of spectroscopic classification of the states observed here and in ref. [2] must remain a matter for speculation. This is especially true since, on the basis of the Isgur-Karl model, two states of even parity are expected in the neighborhood of 2265 MeV/c^2. However it is interesting to note that ref. [7] predicts that both these states should decay predominantly to $\Xi^*(1530)\overline{K}$.

In conclusion, the production of an Ω^{*-} state of mass 2253 ± 13 and width 81 ± 38 MeV/c^2 has been observed at the 4 σ level of significance; the corresponding inclusive cross section for the decay mode $\Xi^*(1530)\overline{K}$ is estimated to be $\sim$ 600 nb.

We are grateful for the support of the technical staffs of SLAC group B, the Universities of Cincinnati and Nagoya. Special thanks are due to R. Bierce and M. Takahashi for their excellent tape management.

REFERENCES

[1] D. Aston et al., contributed talk given by B. Ratcliff in session P09 at the International Europhysics Conference on High Energy Physics, Bari, Italy, July 1985; see S. Cooper, Rapporteur Talk in the Proceedings of this Conference, p. 947 and SLAC-PUB-3819.

[2] S.F. Biagi et al., Zeits. Fur Physik, C31, 33 (1986).

[3] D. Aston et al., SLAC-REP-298;

J. P. Sinervo, Ph. D. Thesis, SLAC-REP-299, May 1986;

N. Awaji, Ph. D. Thesis, (Jan. 1987) Nagoya University (unpublished).

[4] D. Aston et al, Phys. Rev. D32, 2270 (1985).

[5] J.M. Richard, Phys. Lett. 100B, 515 (1981).

[6] N. Isgur and G. Karl, Phys. Rev. D19 2653 (1979).

[7] K.T. Chao, N. Isgur and G. Karl, Phys. Rev. D23 155 (1981).

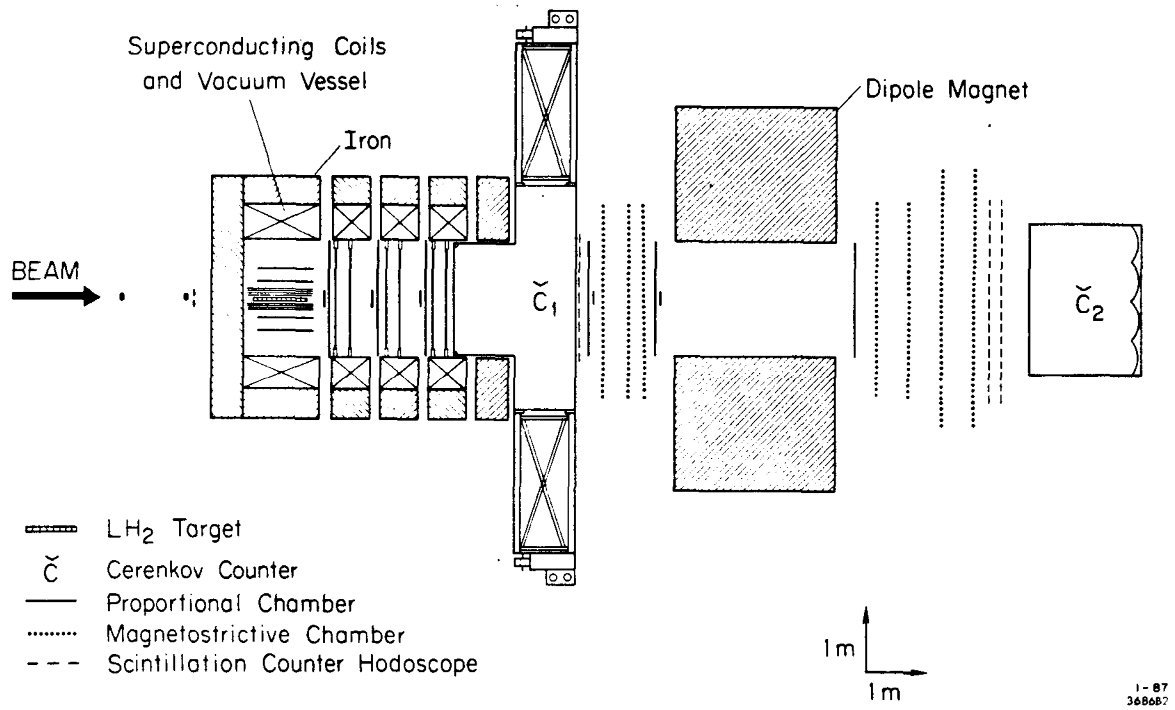
Figure Captions

FIG. 1. The LASS spectrometer.

FIG. 2. Effective mass distributions for Ξ^- events: (a) K^+K^- ; (b) $K^- \pi^+$; (c) $\Xi^-K^-\pi^+$; (d) $\Xi^-\pi^+$.

FIG. 3. (a) The $\Xi^-K^-\pi^+$ mass distribution for events in the Ξ^{*0} mass range ($1510 < M_{\Xi^-\pi^+} < 1555$ MeV/c^2); solid dots are for Ξ^{*0} sideband events ($M_{\Xi^-\pi^+} < 1510$ or $1555 < M_{\Xi^-\pi^+} < 1600$ MeV/c^2); estimated π^- punch-through is represented by open circles. (b) The equivalent $\Xi^-K^-\pi^+$ mass distribution for events in which the "K^-" is an identified π^-.

FIG. 4. (a) The Ξ^{*0} (1530)K^- mass distribution obtained as the difference between the histogram and solid circles in fig. 3(a); the data are presented in 0.1 GeV/c^2 bins except in the region of the peak at $\sim$ 2.25 GeV/c^2, where the bin size is 0.05 GeV/c^2; the curve represents the result of a fit to the data using a single Breit-Wigner peak and a linear background as described in the text; the dotted curve represents the background estimate for this fit. (b) The same distribution as in fig. 4(a) with the fit using two Breit-Wigner peaks described in the text; the contribution from the second peak is represented by the dotted curve.



Superconducting Coils
and Vacuum Vessel
Iron
Dipole Magnet
BEAM
$\check{C}_1$
$\check{C}_2$
LH_2 Target
$\check{C}$ Cerenkov Counter
Proportional Chamber
Magnetostrictive Chamber
Scintillation Counter Hodoscope
1 m
1 m
1-87
3686B2

Fig. 1

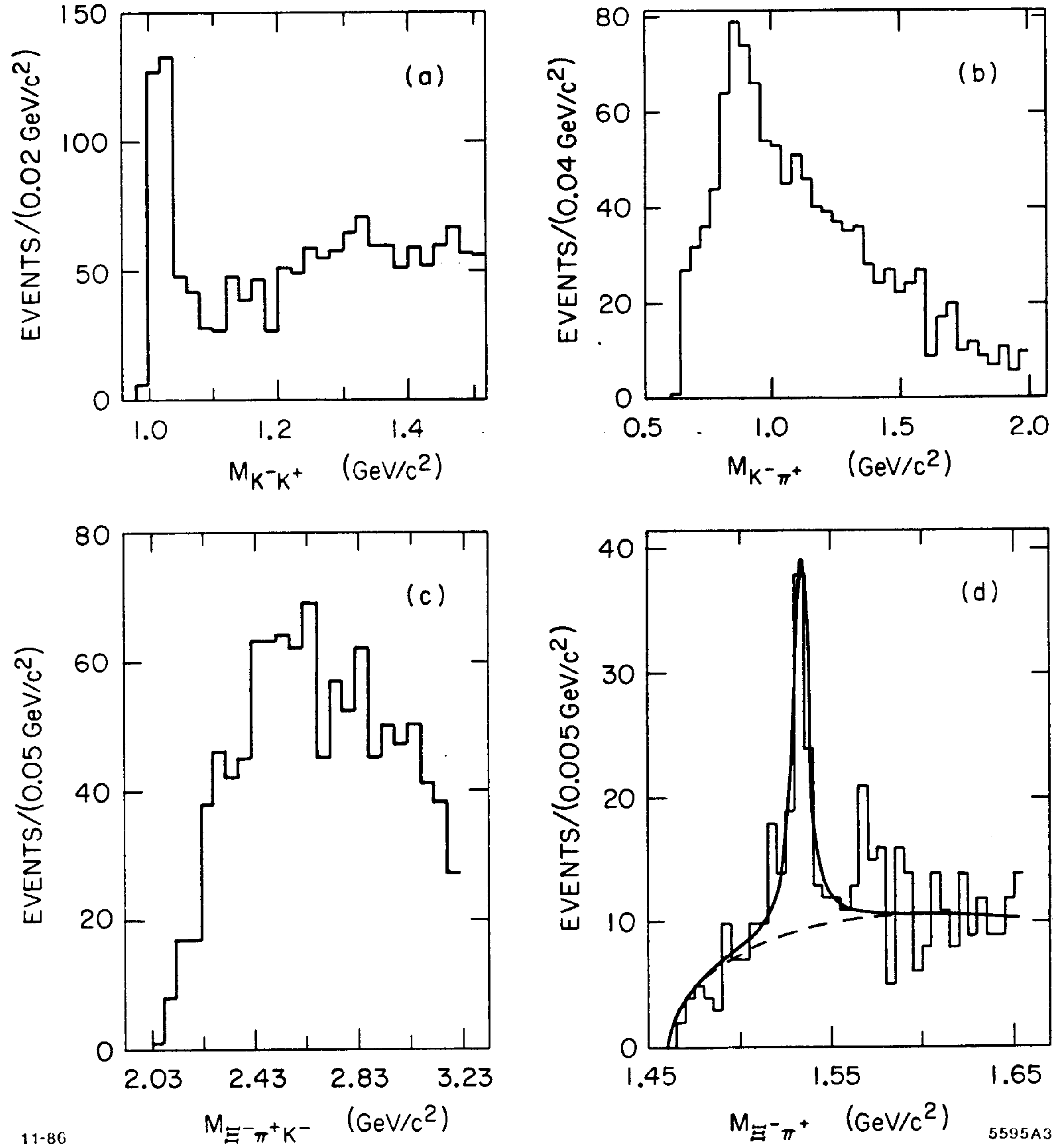

(a)
(b)
(c)
(d)
EVENTS/(0.02 GeV/c2)
EVENTS/(0.04 GeV/c2)
EVENTS/(0.05 GeV/c2)
EVENTS/(0.005 GeV/c2)
$M_{K^-K^+}$ (GeV/c2)
$M_{K^-\pi^+}$ (GeV/c2)
$M_{\Xi^-\pi^+K^-}$ (GeV/c2)
$M_{\Xi^-\pi^+}$ (GeV/c2)
11-86
5595A3

Fig. 2

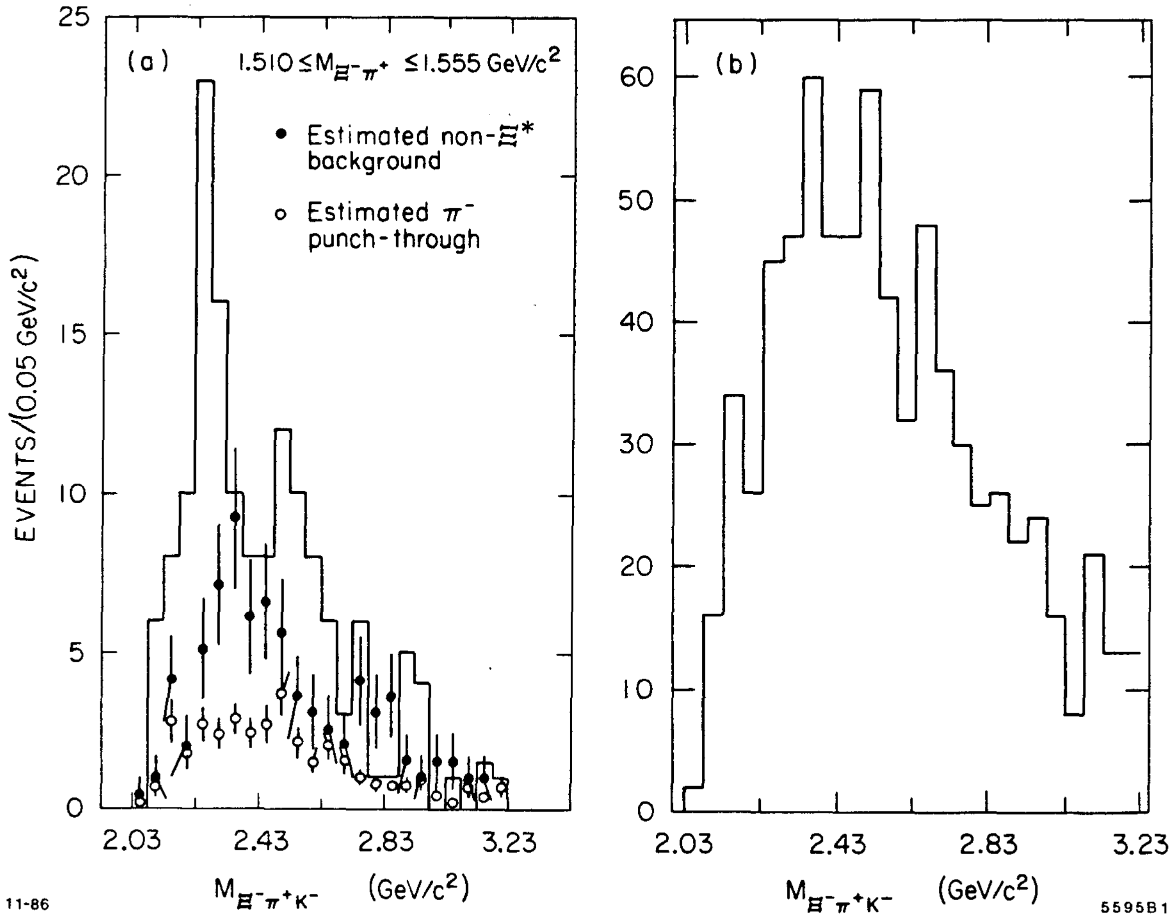
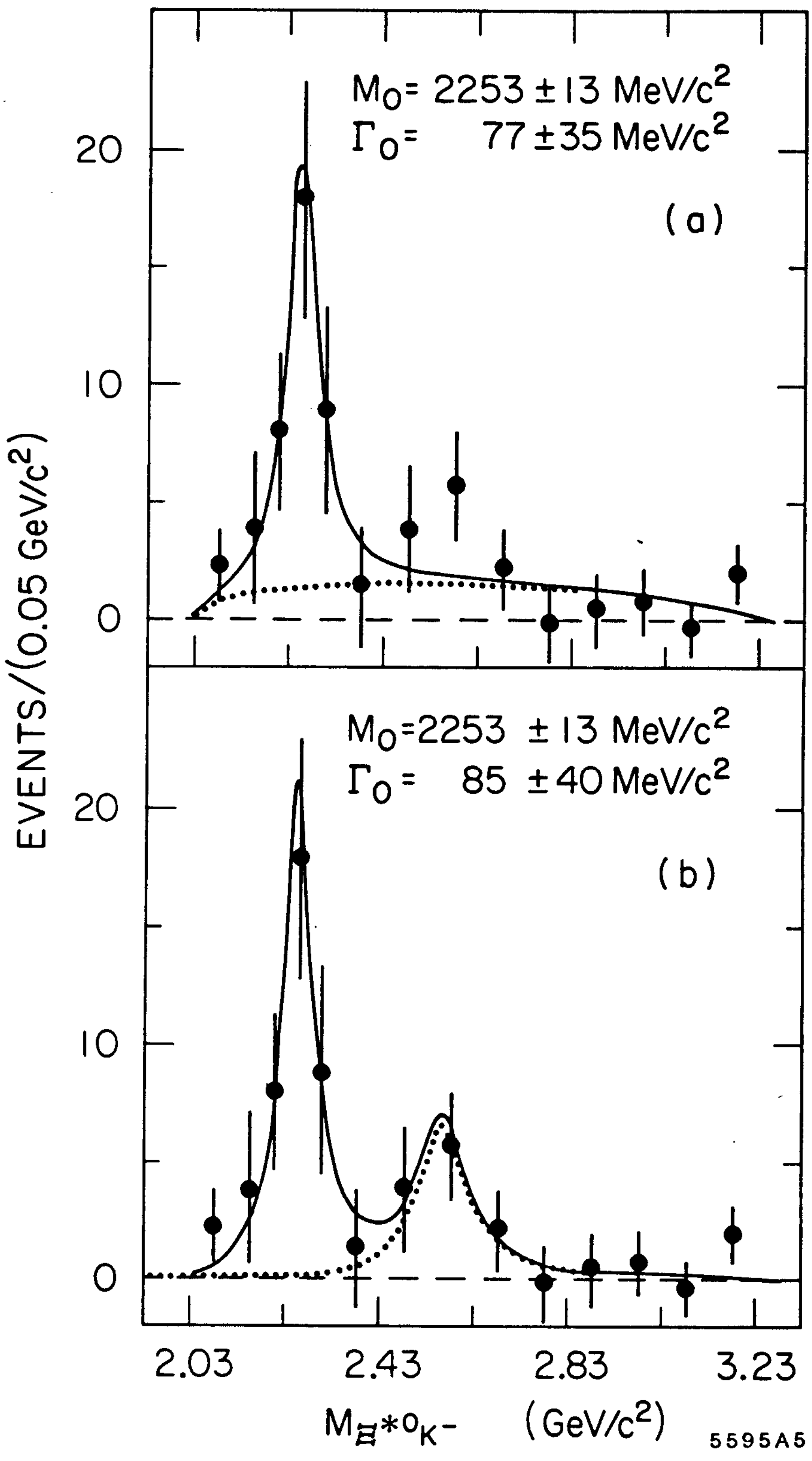

(a)
1.510 ≤ $M_{\Xi^-\pi^+}$ ≤ 1.555 GeV/c^2
● Estimated non-Ξ^* background
○ Estimated π^- punch-through
EVENTS/(0.05 GeV/c^2)
(b)
$M_{\Xi^-\pi^+K^-}$ (GeV/c^2)
2.03
2.43
2.83
3.23
11-86
5595B1

Fig. 3



$M_0 = 2253 \pm 13$ MeV/c^2
$\Gamma_0 = 77 \pm 35$ MeV/c^2
(a)
$M_0 = 2253 \pm 13$ MeV/c^2
$\Gamma_0 = 85 \pm 40$ MeV/c^2
(b)
0
10
20
EVENTS/(0.05 GeV/c^2)
2.03
2.43
2.83
3.23
$M_{\Xi^{*0}K^-}$ (GeV/c^2)
5595A5

Fig. 4