Title
SEARCH FOR A CHARGED MESON IN THE MASS REGION OF 960 MeV

Authors
Barbaro-Galtieri, Angela
Matison, Maxine
Rittenberg, Alan
et al.

Publication Date
1967-12-15

University of California

Ernest O. Lawrence Radiation Laboratory

SEARCH FOR A CHARGED MESON IN THE MASS REGION OF 960 MeV

Angela Barbaro-Galtieri, Maxine Matison,
Alan Rittenberg, and Frank T. Shively

December 15, 1967

Berkeley, California

DISCLAIMER

To be submitted to Physical Review Letters

UCRL-17914
Preprint

UNIVERSITY OF CALIFORNIA

Lawrence Radiation Laboratory
Berkeley, California

AEC Contract No. W-7405-eng-48

SEARCH FOR A CHARGED MESON IN THE MASS REGION OF 960 MeV

Angela Barbaro-Galtieri, Maxine Matison,
Alan Rittenberg, and Frank T. Shively

December 15, 1967

SEARCH FOR A CHARGED MESON IN THE MASS REGION OF 960 MeV*

Angela Barbaro-Galtieri, Maxine Matison,
Alan Rittenberg, and Frank T. Shively†

Lawrence Radiation Laboratory
University of California
Berkeley, California

December 15, 1967

Evidence has been reported in the past few years for a neutral and a charged meson state in the 960-MeV region. The existence of a neutral meson state (η') with $M = 958 \pm 1$ MeV and $\Gamma < 4$ MeV was established by several hydrogen bubble chamber experiments.[1] In the reaction $K^- p \to \Lambda \eta'$, the η' was found to decay strongly into $\pi\pi\eta$ and electromagnetically into $\pi\pi\gamma$, from which decays its quantum numbers were determined to be $IJ^{PG} = 00^{-+}$. Kienzle et al.[2] have reported evidence for a charged meson (δ) with a mass of 963 ± 5 MeV and $\Gamma < 4$ MeV in the reaction $\pi^- p \to p(MM)^-$, with δ^- decaying into one or three charged particles + possible neutrals.[3] Allison et al. report evidence for the reaction $K^- p \to \Sigma^{\pm} \pi^0 \delta^{\mp}$ with $\delta^{\mp} \to \pi^{\mp}\pi^+\pi^-$ at 6.0 GeV/c incident momentum.[4] The coincidence of the mass and width of the δ and η' leads to two possible interpretations: (a) δ and η' are the same particle; in this case not only the isospin, but also the other quantum numbers of the η' are questioned; (b) δ and η' are two different particles; this interpretation has led to theoretical discussions on mass degeneracy,[5] to a possible assignment of the δ to a $^3P_0$ configuration in the quark-antiquark model for meson states,[6] and to the conjecture that δ might be the 0^{++} daughter trajectory of the ρ

meson.[7] We report here an experiment which rules out possibility (a) and sets some upper limits on the cross section for production of the δ in $K^- n \to \Lambda\delta^-$ with subsequent decay of the δ into various states.

In this experiment the 72-inch bubble chamber, filled with deuterium, was exposed to a K^- beam at momenta 2.11 and 2.65 GeV/c. The reaction studied was

$$K^- d \to \Lambda X^- (p_s), \qquad (1)$$

where X^- is a negative meson decaying into two to five pions or pions plus a γ; the spectator proton, (p_s), was measurable in 30% of the events. Excluding the spectator proton from the number of prongs, these events were found in the topologies of a V and 1 prong (13 000 measured events) and of a V and 3 prongs (5 000 measured events). The events were measured on Franckenstein and spiral-reader measuring machines, and our standard programs (PKG, DST-EXAM, SUMX) were used for the analysis.[8] If the spectator proton was not visible or was too short to be measured, it was assigned a momentum equal to zero, with appropriate errors in the x, y, and z components, and fitted as if it were measured.[9] For the following analysis, only events having a proton momentum $P_{sp} < 280$ MeV/c were used.

If the η' were isospin 1, the cross section for $K^- n \to \Lambda\eta'^-$ would be twice as large as that for $K^- p \to \Lambda\eta'^0$, and the latter cross section we know at both momenta from our hydrogen data.[10] We proceed to test the isospin-1 hypothesis under varying assumptions.

(a) We assume, for the moment, that the charged η' would appear only in the reactions

$$K^- n \rightarrow \Lambda\pi^-\pi^+\pi^- MM\,, \qquad (2)$$

$$K^- n \rightarrow \Lambda\pi^- MM\,, \qquad (3)$$

where MM consists of at least two neutrals. This would be the case if the only decay modes of η'^- were $\pi^-\pi^0\eta$ and $\pi^-\pi^0\gamma$. Figure 1a shows a plot of the invariant mass squared of the negative system recoiling against the Λ for these reactions for momentum transfer to the Λ, $\Delta^2 \leq 0.7\ (\mathrm{GeV}/c)^2$. Using the effective path length of this experiment for Reactions (2) and (3), we expect a total of 378 ± 32 events above background in the interval 960 ± 45 MeV.[11] We find no enhancement of statistical significance, and, drawing a smooth background, we conclude that $N_{\eta'^-} < 42$ events,[12] or the cross section for $K^- n \rightarrow \Lambda\eta'^-$ (all Λ) is $\sigma < 25\,\mu b$ against an expected $220 \pm 18\ \mu b$.

(b) Figure 1b shows the situation if we make the additional assumption that the branching ratio for $\eta'^- \rightarrow \pi^-\pi^0\eta$ is the same as for $\eta'^0 \rightarrow \pi^-\pi^+\eta$; from our H_2 data, this ratio is found to be 0.42 ± 0.03, independent of any isospin assignment for the η'. In order to reduce the background under a possible $\pi^-\pi^0\eta$ enhancement, for Reaction (2) we impose the condition that at least one $\pi^+\pi^-$ combination satisfies $M(\pi^+\pi^-) \leq M_\eta$; for Reaction (3) the η is neutral and we require that $MM \geq M_\eta + M_{\pi^0}$. With these conditions, appropriately adjusted to take errors into account, we obtain the plot of Fig. 1b. The expected number of events is now 158 ± 18, and we find $N_{\eta'} < 21$ events,[12] or the cross section for $K^- n \rightarrow \Lambda\eta'^-$ (all Λ, $\eta'^- \rightarrow \eta\pi^-\pi^0$) is $\sigma < 12\,\mu b$ against an expected $92 \pm 11\ \mu b$.[13]

(c) We have shown thus far that there is no evidence for a charged η' decaying into $\pi^-\pi^0\eta$, $\pi^-\pi^0\gamma$, or any mode involving two or more neutrals. To definitely settle the question of the isospin of the η', we now investigate all the other possible modes, which would be included in the following reactions:

$$K^- n \rightarrow \Lambda\pi^-\pi^0 \text{ (or } \gamma), \tag{4}$$

$$K^- n \rightarrow \Lambda\pi^-\pi^+\pi^- , \tag{5}$$

$$K^- n \rightarrow \Lambda\pi^-\pi^+\pi^-\pi^0 \text{ (or } \gamma) . \tag{6}$$

These modes might be allowed electromagnetically for the η'^-, even though the corresponding modes for η'^0 are absent in the H_2 data.

Figure 2 shows the 2π, 3π, 4π, $\pi^-\rho$, $\pi^-\omega$, and $\pi^-\eta$ mass distributions. The shaded histograms refer to low-Δ^2 events [$\Delta^2 \leq 0.7$ (GeV /c)^2]; the unshaded histograms contain all the events, which we will use later to set upper limits for production of the δ. The curves on the latter distributions represent fits obtained with the program MURTLEBERT,[14] which takes into account all the possible resonant states present in any of the mass combinations. The dashed lines drawn on the shaded histograms represent the background estimated from the adjacent bins. Each plot also shows the width which the η'^- would have, taken according to our resolution in the different final states. The six low-Δ^2 plots show no statistically significant enhancement in the 960-MeV region.

By the analysis of Figs. 1 and 2 it is clear that there is no evidence at all for production of the η'^-, which should appear in the distributions with a total of $N = 378 \pm 32$ events above background. Since even the possibility of decays other than $\pi\pi\eta$ and $\pi\pi\gamma$ for a charged η' is excluded, we conclude that the isospin of the η' is definitely $I = 0$.

We now turn to the δ. There is no evidence in our data for production of any meson resonance in the 960-MeV region for the reaction $K^- n \rightarrow \Lambda X^-$. With the isospin of the η' established, we may take the upper limits for a signal in this region as being those for production of the δ. Table I summarizes these limits for the nine processes considered in this paper, for all events and for low Δ^2.

We wish to thank the 72-inch bubble chamber crew, our scanning and measuring group, and the spiral reader programmers in addition to the other physicists associated with the early part of this experiment. We are especially grateful to Dr. Frank Solmitz for discussions in many phases of the analysis. Finally, we gratefully acknowledge the continued support and encouragement of Professor Luis W. Alvarez.

Footnotes and References

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

†Present address: Facultés de Sciences, Institute de Physique Nucléaire, Paris 5, France.

1. A complete list of references can be found in A. H. Rosenfeld, N. Barash-Schmidt, A. Barbaro-Galtieri, W. J. Podolsky, L. R. Price, P. Söding, C. G. Wohl, M. Roos, and W. J. Willis, UCRL-8030, Sept. 1967 (unpublished).

2. W. Kienzle, B. C. Maglić, B. Levrat, F. Lefebvres, D. Freystag, and H. R. Blieden, Phys. Letters <u>19</u>, 438 (1965).

3. Evidence for a positively charged δ has been reported in another missing-mass spectrometer experiment in the reaction $pp \rightarrow d\delta^+$ by J. Oostens, P. Chavanon, M. Crozon, and J. Tocqueville, Phys. Letters <u>22</u>, 708 (1966). However, the same experiment was repeated at the same incident energy and the evidence for the δ^+ has now disappeared; see M. Banner, J. Cheze, J. L. Hamel, G. Marel, J. Teiger, J. Zsembery, P. Chavanon, M. Crozon, and L. K. Rangan, Phys. Letters <u>25B</u>, 569 (1967).

4. W. W. M. Allison, A. Cruz, W. Schrankel, M. M. Hague, S. K. Tuli, P. J. Finney, C. M. Fisher, J. D. Gordon, R. M. Turnbull, R. Erskine, K. Sisterson, K. Paler, P. Chaudhuri, A. Eskreys, and S. J. Goldsack, Phys. Letters <u>25B</u>, 619 (1967).

5. S. F. Tuan and Tai Tsan Wu, Phys. Rev. Letters <u>18</u>, 349 (1967). These authors suggest that the η' and the δ might be members of a new pseudoscalar octet along with an as-yet-undetected K^* at $M \approx 960$ MeV. In this case the main decay modes for the δ should be $\rho\pi$ and 3π.

6. R. H. Dalitz, in <u>Proceedings of the XIII International Conference on High-Energy Physics at Berkeley</u> (University of California Press, 1967, Berkeley), page 213. The quantum numbers for the δ would be $J^{PG} = 0^{+-}$ in this case, and $\delta \to \eta\pi$ would be the favored decay mode.

7. D. Freedman, in Symposium on Regge Poles, Argonne National Laboratory, December 1966, page 108. Note that the G parity in this case is positive, whereas it is negative in the quark model; $\delta \to 4\pi$ would be the main decay mode.

8. All ambiguous events were checked on the scanning table in an attempt to resolve the ambiguity. For about 3% of the events it was not possible to distinguish between two possible fits, and in this case the one with the larger confidence level was accepted.

9. For the events with a four-constraint (4-c) fit, the fitted spectator proton momentum distribution is in agreement with the one expected from the impulse approximation, and the mass resolution is not affected by this procedure. However, for the (1-c) fits, the momentum distribution is shifted toward zero, resulting in a mass resolution of the order of 30 MeV, full width at half maximum, as calculated from the width of the η and ω peaks. Finally for the (0-c) final states the resolution is ≈ 45 MeV (calculated again from the η and ω peaks, when the (1-c) events are treated as (0-c)).

10. The cross sections for the reaction $K^- p \to \Lambda\eta'$, for visible Λ decay, at 2.11 and 2.65 GeV/c are 89 ± 8 μb and 57 ± 4 μb for momentum transfer squared $\Delta^2 \leq 0.5$ $(\mathrm{GeV}/c)^2$. In what follows we take a Δ^2 cutoff at 0.7 $(\mathrm{GeV}/c)^2$ in order to take into account the poor resolution for (0-c) fits.

11. The effective path length calculation takes into account the scanning and measuring efficiency, as well as the correction for short Λ cutoff, the cutoff on the spectator momentum, and the Glauber correction for the screening of the neutron in the deuterium nucleus. The path lengths are $\lambda = (1.35 \pm 0.10)$ events/μb and (1.21 ± 0.10) events/μb at 2.11 and 2.65 GeV/c respectively. For Table I we will use a larger sample of data in Reaction (2).

12. This and all subsequent limits are determined by calculating the number of events ($N_{3\Delta}$) above background (N_b), which would require a three-standard-deviation downward fluctuation to produce no signal ($N_{3\Delta} = 3\,(N_b + N_{3\Delta})^{1/2}$). These limits are thus at the 99% confidence level.

13. A previous similar experiment by H. J. Martin, R. R. Crittenden, and L. S. Schroeder, Phys. Letters 22, 352 (1966), has reported (5 ± 4) events seen where (19 ± 6) events were expected. At the Heidelberg Conference on Elementary Particles (Sept. 1967) the Amsterdam-Bologna-Paris-Rehovoth-Saclay Collaboration (Abstract 131) reported results similar to ours.

14. J. Friedman, MURTLEBERT, Alvarez Programming Group Note P-156, 1966.

Figure Captions

Fig. 1. Mass-squared distribution of the π^-MM and $\pi^-\pi^+\pi^-$MM systems in Reactions (2) and (3). Only events with small momentum transfer to the Λ [$\Delta^2 \leq 0.7$ (GeV/c)^2] are plotted. (a) Search for $\eta'^- \to \pi^-$ MM and $\pi^-\pi^+\pi^-$MM, (b) search for $\eta'^- \to \pi^-\pi^0\eta$. The shaded histograms refer to events with three charged pions. The arrows indicate the position of the η'^- mass and have bars representing twice the resolution of the mass squared. The expected number of η'^- events (N_e) above background for isospin one is given in each histogram.

Fig. 2. Search for decay modes of η'^- other than the known decay modes of η'^0. (a) $X^- \to \pi^-\pi^0$, (b) $X^- \to \pi^-\pi^+\pi^-$, (c) $X^- \to \pi^-\pi^+\pi^-\pi^0$, (d) $X^- \to \pi^-\rho$, (e) $X^- \to \pi^-\omega$, (f) $X^- \to \pi^-\eta$. The position of the η'^- is indicated by the arrows, with error bars representing twice the resolution for each plot. The events with small momentum transfer to the Λ [$\Delta^2 \leq 0.7$ (GeV/c)^2] are shown in the shaded histograms. The solid curves represent fits to each mass plot as explained in the text. The dashed lines represent our estimated background for the low-Δ^2 plots.

Table I. Cross section limits for production of a negative meson at 960 MeV.

Reaction	All events			$\Delta^2 \leq 0.7\ (\mathrm{GeV}/c)^2$		
	N_{ab} [a]	$N_{3\Delta}$ [b]	σ (μb) [c]	N_{ab} [a]	$N_{3\Delta}$ [b]	σ (μb) [c]
$K^- n \rightarrow \Lambda X^-$						
1. $X^- \rightarrow \pi^- \pi^0$	+34±16	44	< 26	+13	32	< 19
2. $X^- \rightarrow \pi^-$ MM	+20	64	< 37	+17	42	< 25
3. $X^- \rightarrow \pi^- \pi^+ \pi^-$	- 4±14	38	< 16	0	24	< 10
4. $X^- \rightarrow \pi^- \rho$	+ 8±11	27	< 11	- 1	18	< 8
5. $X^- \rightarrow \pi^- \pi^+ \pi^- \pi^0$	+ 7	34	< 14	+ 5	22	< 9
6. $X^- \rightarrow \pi^- \eta$	+11±10	32	< 13	+ 9	21	< 9
7. $X^- \rightarrow \pi^- \omega$	-19±9	30	< 12	+ 4	19	< 8
8. $X^- \rightarrow \pi^- \pi^+ \pi^-$ MM	- 1	13	< 5	- 2	10	< 4
9. $X^- \rightarrow \pi^- \pi^0 \eta$	+ 7	28	< 16	- 7	21	< 12
$X^- \rightarrow$ 1 charged	+54	71	< 42	+30	50	< 29
$X^- \rightarrow$ 3 charged	+ 2	49	< 20	+ 3	30	< 12

(a) N_{ab} = number of events seen above background (those values of N_{ab} having an error were obtained from fitting as discussed in the text; the remainder were determined by estimating the background).

(b) For the definition of $N_{3\Delta}$, see footnote 12.

(c) σ = upper limit for the cross section, as obtained by combining the 2.11- and 2.65-GeV/c data, and corrected for neutral Λ decay (there is no significant difference between the values for the two momenta taken separately).

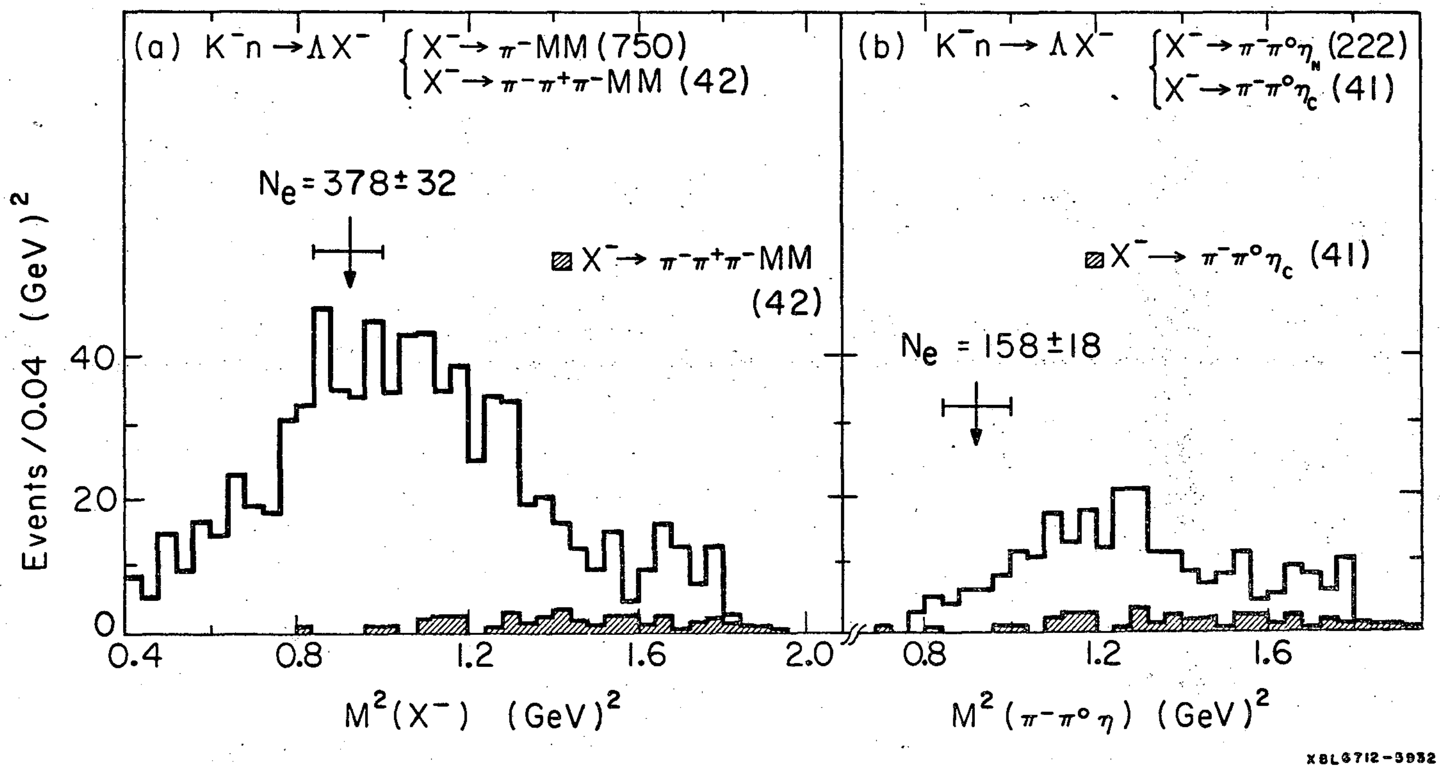
(a) K⁻n → ΛX⁻
X⁻ → π⁻MM (750)
X⁻ → π⁻π⁺π⁻MM (42)
Nₑ = 378 ± 32
X⁻ → π⁻π⁺π⁻MM (42)
Events / 0.04 (GeV)²
M²(X⁻) (GeV)²
(b) K⁻n → ΛX⁻
X⁻ → π⁻π°η_N (222)
X⁻ → π⁻π°η_c (41)
Nₑ = 158 ± 18
X⁻ → π⁻π°η_c (41)
M²(π⁻π°η) (GeV)²
XBL 6712-5932

Fig. 1.

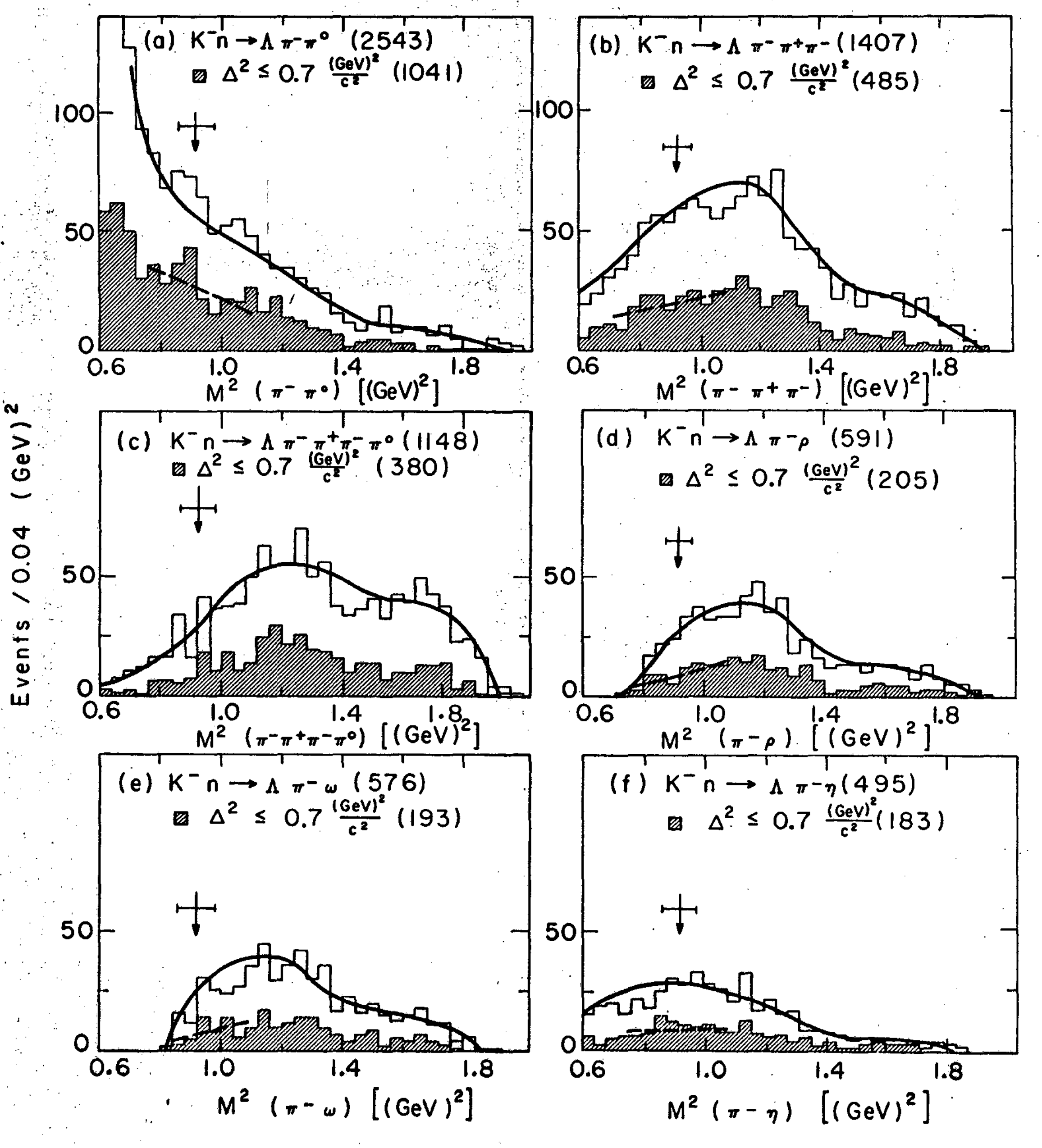
(a) K⁻n → Λ π⁻π⁰ (2543)
Δ² ≤ 0.7 (GeV)²/c² (1041)
100
50
0
0.6
1.0
1.4
1.8
M² (π⁻ π⁰) [(GeV)²]
(b) K⁻n → Λ π⁻π⁺π⁻ (1407)
Δ² ≤ 0.7 (GeV)²/c² (485)
M² (π⁻ π⁺ π⁻) [(GeV)²]
(c) K⁻n → Λ π⁻π⁺π⁻π⁰ (1148)
Δ² ≤ 0.7 (GeV)²/c² (380)
M² (π⁻π⁺π⁻π⁰) [(GeV)²]
(d) K⁻n → Λ π⁻ρ (591)
Δ² ≤ 0.7 (GeV)²/c² (205)
M² (π⁻ρ) [(GeV)²]
(e) K⁻n → Λ π⁻ω (576)
Δ² ≤ 0.7 (GeV)²/c² (193)
M² (π⁻ω) [(GeV)²]
(f) K⁻n → Λ π⁻η (495)
Δ² ≤ 0.7 (GeV)²/c² (183)
M² (π⁻η) [(GeV)²]
Events / 0.04 (GeV)²

Fig. 2.