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We have searched for isospin-2 hyperon resonances produced in K^-n interactions at 2.11 and 2.65 GeV/c and decaying into $\Sigma^-\pi^-$ or $\Sigma^-\pi^-\pi^0$. We find no evidence for any such state with $M \leq 2300$ MeV, and obtain a cross section upper limit of 30 μb, with 99% confidence level.

Recent experiments on K^+p total cross sections (hypercharge state Y = 2) have shown the presence of four enhancements, three in the isospin I = 1 state and one in the I = 0 state, which might be attributed to resonances.[1] An alternative explanation can be found for at least the first I = 1 enhancement;[2] however, at this time, the large (≈ 6 mb) bump in the I = 0 isospin state (at M = 1865 MeV) does not seem to have any other plausible explanation. All the other established baryon resonances can be classified in singlets, octets, and decuplets of the SU(3) symmetry scheme, but Y = 2 states would belong to higher representations ($\overline{10}$ for I = 0, 27 for I = 1).

Investigation of the existence of other resonances that would belong to such higher representations is relevant for the quark model because as it stands now it cannot accommodate high Y or I states, since a five-quark structure ($qqqq\bar{q}$) would be needed to describe such states. Horn et al.,[3] using the five-quark model, obtained some selection rules which forbid the decay mode B+P (spin-1/2 baryon + pseudoscalar meson) for some spin-parity assignments of high Y, I states, and they suggest that B+P+P decays should also be investigated. Only the $\Sigma^- \pi^-$ $I = 2$ state has been investigated so far, and it failed to show any structure at masses below $M = 1800$ MeV.[4] We report here the results of a search for $I = 2$, $Y = 0$ resonances decaying into the $\Sigma^- \pi^-$ and $\Sigma^- \pi^- \pi^0$ channels, with $M \leqslant 2300$ MeV.

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 reactions studied were

$$K^- d \rightarrow (p_s)\ \Sigma^- \pi^+ \pi^- \qquad (1)$$

and

$$K^- d \rightarrow (p_s)\ \Sigma^- \pi^+ \pi^- \pi^0\ , \qquad (2)$$

where (p_s) indicates the spectator proton, which was measurable in 30% of the events. A total of 5000 events was measured on Franckenstein measuring machines and processed with the LRL standard programs (PKG, DST-EXAM, SUMX). For the events in which 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, z components, and then fitted as if it were measured. This method turns out to be very good for four-constraint (4-c) fits, though it results in a slightly worse resolution for the (1-c) fits.[5] Almost all events were checked on the scanning table, either to confirm the choice of the programs or to resolve the ambiguity of the fit whenever necessary. Only about 3% of the events remained ambiguous after this check. For the following analysis, only events having a proton momentum $P_{sp} < 280$ MeV/c were used.

Figure 1a shows the invariant-mass-squared distribution for the $\Sigma^-\pi^-$ $I_z = 2$ final state in reaction (1); Figs. 1b and 1c show the $\Sigma^-\pi^-$ and $\Sigma^-\pi^-\pi^0$ $I_z = 2$ final states in reaction (2). The plots show no obvious enhancement at any mass. In order to determine the expected shape of the mass distributions for the case in which no I = 2 resonance is present, we have investigated the effects on these distributions of known resonances that might be produced in the reactions under study. This investigation has been made with the aid of a maximum-likelihood program, MURTLEBERT,[6] which fits the events to a frequency function obtained by incoherently adding phase space to Breit-Wigner (or Gaussian) shaped resonances and can use as parameters the mass, width (M, Γ), and percentage of each resonance. As a result of this method, the reflections of resonances on the different mass combinations are properly treated. The events at the two momenta have been fitted independently and, with a few exceptions to be discussed later, no difference was found in the positions and widths of the resonances at the two momenta.

Table I lists the resonance processes which, added to phase space, give the best fit for reactions (1) and (2) at the two momenta, and the cross sections for the two reactions.[7] Reaction (1) is dominated by production of the ρ meson in the $\pi^+\pi^-$ final state and of the $\Lambda(1520)$ in the $\Sigma^-\pi^+$ final state. Reaction (2) is dominated by the production of the ω meson and the $\Sigma(1385)$. In Fig. 2 we show some of the mass plots, with curves corresponding to the fits of Table I. We turn now to a discussion of these fits.

The baryon states, $\Lambda(1405)$, $\Lambda(1518)$, and $\Sigma(1385)$, have the expected masses and widths within the accuracy of this experiment. However, we list three different values of M and Γ for states in the mass interval 1670 to 1705 MeV. There are four known resonances in this energy region,[8] therefore we possibly see the production of several of these states decaying into $\Sigma^-\pi^+$ or $\Sigma^-\pi^+\pi^0$. The Y^{*0} (1840) has a narrow width and might be identified with the Λ(1860), Γ = 34 MeV and $J^P = 7/2^+$, reported by Armenteros et al.[9]

The distribution of the invariant mass squared of the three-pion final state is shown in Figs. 2c and 2d. The η and ω are clearly produced at both momenta. The 2.11-GeV/c data show an enhancement at a mass of ≈1.0 GeV (28 ± 13 events) which also appears in the low-Δ^2 events in both plots. Since we cannot distinguish between a π^0 and a γ, a possible explanation of this enhancement is the ππγ decay mode of the η'. Although the mass of the η' is 960 MeV, two systematic effects present in our data would cause an η' signal to appear at a higher mass.[10] In order to determine the number of $\eta' \to \pi\pi\gamma$ events we would expect to see, we have looked at the reaction $K^-d \to (p_s)\Sigma^-\eta'$, with $\eta' \to \eta_N \pi^+\pi^-$ (including only the neutral η decays). We found, again at a slightly high mass, 28 ± 7 events (20 ± 5 at low Δ^2) for the 2.11-GeV/c data and 18 ± 8 events (9 ± 4 at low Δ^2) for the 2.65-GeV/c data. The η' branching ratios[11] predict these same numbers of events for $\eta' \to \pi^+\pi^-\gamma$. What we see agrees numerically with the η' interpretation, leaving no evidence for the H meson in these data.[12]

As for the I = 2 hyperon states, the curves shown in Fig. 1 represent the expected mass distributions corresponding to the fits reported in Table I. These fits assume that no Y_2^* resonance is present, and include all known resonances that appear at a level ⩾ 2 standard deviations. The curves seem to fit the data very well except for a small fluctuation in the $\Sigma^-\pi^-\pi^0$ mass distribution. The result of the fit for this small enhancement was (3 ± 2)% of the 2.65-GeV/c data, therefore of no statistical significance. This error, as well as the errors quoted in Table I, includes all the uncertainties of the multi-parameter fit, and therefore it is larger than that obtained by taking the statistical error on the projected mass plot. For the purpose of calculating cross-section upper limits we have fitted the data at the two momenta together. This reduces the errors quoted in Table I by about 30%; from these errors it follows that a three-standard-deviation effect corresponds to ≈4% of the combined data. For mass above 2150 MeV only the 2.65-GeV/c data contribute, and a different upper limit is evaluated. As for the possibility that a narrow $\Sigma^-\pi^-$ or $\Sigma^-\pi^-\pi^0$ resonance might be spread out and thus not observed, Table I shows that our resolution is very good for the analogous $\Sigma^-\pi^+$ and $\Sigma^-\pi^+\pi^0$ mass combinations (note, for example, the $\Lambda(1705) \to \Sigma^-\pi^+\pi^0$ with a 35-MeV width). We quote the following upper limits for a Y_2^*:

$$\text{For } M < 2150 \text{ MeV} \quad \Gamma < 60 \text{ MeV} \quad \sigma < 20\ \mu\text{b},$$

$$\Gamma < 120 \text{ MeV} \quad \sigma < 30\ \mu\text{b},$$

$$\text{for } M < 2300 \text{ MeV} \quad \Gamma < 60 \text{ MeV} \quad \sigma < 30\ \mu\text{b},$$

$$\Gamma < 120 \text{ MeV} \quad \sigma < 40\ \mu\text{b},$$

with a 99% confidence level.[13]

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5. The resolution for the invariant mass of pairs or triplets of particles other than the 3π mass is quite good, as can be checked by comparing the widths used to fit the data (Table I) with those quoted in the world compilation by A. H. Rosenfeld, N. Barasch-Schmidt, A. Barbaro-Galtieri, L. R. Price, P. Söding, C. G. Wohl, M. Roos, and W. J. Willis, Rev. Mod. Phys. 40, 77 (1968). For the three-pion system the resolution is worse; this results from the spreading of the π^0 momentum produced by the uncertainty in the momentum of the unmeasured spectator proton. In the 2.11-GeV/c events, which have a larger beam momentum spread than do the 2.65-GeV/c events, this effect is increased.

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

7. The effective path lengths were calculated with scanning and measuring efficiency taken into account, as well as the detection efficiencies for Σ^- (a length cutoff of 3 mm was used), the cutoff on the spectator proton momentum, and the Glauber correction for the screening of the neutron in the deuterium nucleus. The path lengths were $\lambda = 1.61 \pm 0.21$ events/μb and 1.62 ± 0.21 events/μb at 2.11 and 2.65 GeV/c, respectively.

8. See the particle data compilation of Ref. 5. Note that the $\Lambda(1705)$, which we find in the neutral but not in the charged $\Sigma\pi\pi$ state, has previously been detected only in formation experiments.

9. R. Armenteros, M. Ferro-Luzzi, D. W. G. Leith, R. Levi-Setti, A. Minten, R. D. Tripp, H. Filthuth, V. Hepp, E. Kluge, H. Schneider, R. Barloutaud, P. Gianet, J. Meyer, and J. P. Porte, Nucl. Phys. B3, 592 (1967).

10. The upward displacement (about 40 MeV at 2.11 GeV/c and ≈ 25 MeV at 2.65 GeV/c) of the mass of the η' arises from two different sources: (a) The use of the π^0 mass instead of the γ mass produces an effect that amounts to ≈ 15 MeV, as we found by refitting the events with the γ instead of the π^0 mass. (b) The uncertainty in the π^0 momentum in the 70% of the events in which the spectator is not visible produces an additional shift not present in those events with a measured spectator. This was confirmed by the fact that when the latter events were refitted, ignoring the measurement of the spectator proton, there was an upward shift (larger at 2.11 than at 2.65 GeV/c) in the three-pion mass spectrum in the 1.0-GeV region. This refitting produced no such shift in the ω region, consistent with the fact that the ω appears at its correct mass in our events.

11. The ratio $R = \frac{\eta' \to \pi^+\pi^-\gamma}{\eta' \to \pi^+\pi^-\eta_N + (\pi^0\pi^0\eta_C)_B}$ is $R = 0.96 \pm 0.12$, where $(\pi^0\pi^0\eta_C)_B$ indicates the background of this decay mode under the $\pi^+\pi^-\eta_N$ (A. Rittenberg, Lawrence Radiation Laboratory, private communication).

12. At the Heidelberg Conference we had reported a 2.5-standard-deviation effect at a mass of about 990 MeV which was attributed to the H meson. See I. Butterworth, in Proceedings of the Heidelberg International Conference on Elementary Particles (North-Holland Publishing Company, Amsterdam, 1968), p. 11. However, an increase of about 35% in the amount of data and a better understanding of the systematic mass shift and resolution in our data led us to the present conclusions.

The evidence for the existence of the H meson is currently less than two standard deviations in only one experiment. See A. Barbaro-Galtieri and P. Söding in "Is There Evidence for the H Meson?" (UCRL-18271, June 1968) to be published in Proceedings of the Philadelphia Conference on Meson Spectroscopy (W. A. Benjamin, Inc., New York, 1968).

13. To check the error calculations such resonances were artificially added to the data. The resulting fits correspond to 3.5 standard deviations from "no resonance."

FIGURE LEGENDS

Fig. 1. Plots of all the possible $I_z = 2$ mass combinations in reactions (1) and (2). The two momenta have been combined in these plots in order to increase statistics. (a) $M^2(\Sigma^-\pi^-)$ for reaction (1); (b) $M^2(\Sigma^-\pi^-)$ for reaction (2). (c) $M^2(\Sigma^-\pi^-\pi^0)$ for reaction (2). The curves correspond to the best fits of Table I, which do not need any resonance in the $I = 2$ system.

Fig. 2. (a-b) The mass squared distributions of the $\Sigma^-\pi^+$ system for reaction (1). (c-d) The mass squared distribution of the three pions in reaction (2); dashed histograms refer to events with low momentum transfer to the Σ^-, $\Delta^2 < .6\ \mathrm{GeV}^2/c^2$. The curves correspond to the best fit reported in Table I.

Table I. Best fit to the data of reactions (1) and (2).

Description of model		2.1 GeV/c	2.7 GeV/c
Reaction (1)	$K^- n \to \Sigma^- \pi^+ \pi^-$	876 events	605 events
Process	M, Γ (MeV)	%	%
$K^- n \to Y^{*0} \pi^-$	1405,35	6.7 ± 1.3	10.8 ± 1.7
	1518,18	21.3 ± 1.9	18.9 ± 2.2
	1675,55	10.4 ± 2.0	8.8 ± 2.0
	1840,35	2.5 ± 1.3	7.0 ± 1.8
$K^- n \to \Sigma^- \rho^0$	760,120	35.9 ± 3.4	21.8 ± 3.4
σ_{tot}	for reaction (1) (μb)	545 ± 70	370 ± 50
Reaction (2)	$K^- n \to \Sigma^- \pi^+ \pi^- \pi^0$	775 events	892 events
Process	M, Γ (MeV)	%	%
$K^- n \to Y^{*0} \pi^- \pi^0$	1410,30	7.1 ± 2.0	6.3 ± 1.6
	1520,20	4.1 ± 1.6	5.6 ± 1.5
	1675,35		3.9 ± 1.6
$K^- n \to Y^{*-} \pi^+ \pi^-$	1390,45	10.6 ± 2.4	5.0 ± 1.8
$K^- n \to Y^{*0} \pi^-$	1705,35	3.6 ± 1.5	2.1 ± 1.0
	2190,60		3.2 ± 1.8
[a] $K^- n \to \Sigma^- \eta$	548,40	2.6 ±0.7	2.2 ± 0.6
[a] $K^- n \to \Sigma^- \omega$	783,40	27.1 ± 2.3	14.5 ± 1.5
[a] $K^- n \to \Sigma^- \eta'$	960,60	3.6 ± 1.7	3.1 ± 1.6
σ_{tot}	for reaction (2) (μb)	480 ± 62	550 ± 72

a. See footnotes 4 and 10 for a discussion of the resolution and mass shifts for the three meson states. For the ω at 2.11 GeV/c we have used M = 789 MeV and Γ = 80 MeV. For the η' we have used (1000,50) and (985,70) at 2.11 GeV/c and 2.65 GeV/c respectively (at 2.11 GeV/c the η' is at the edge of phase space and thus requires a smaller width).

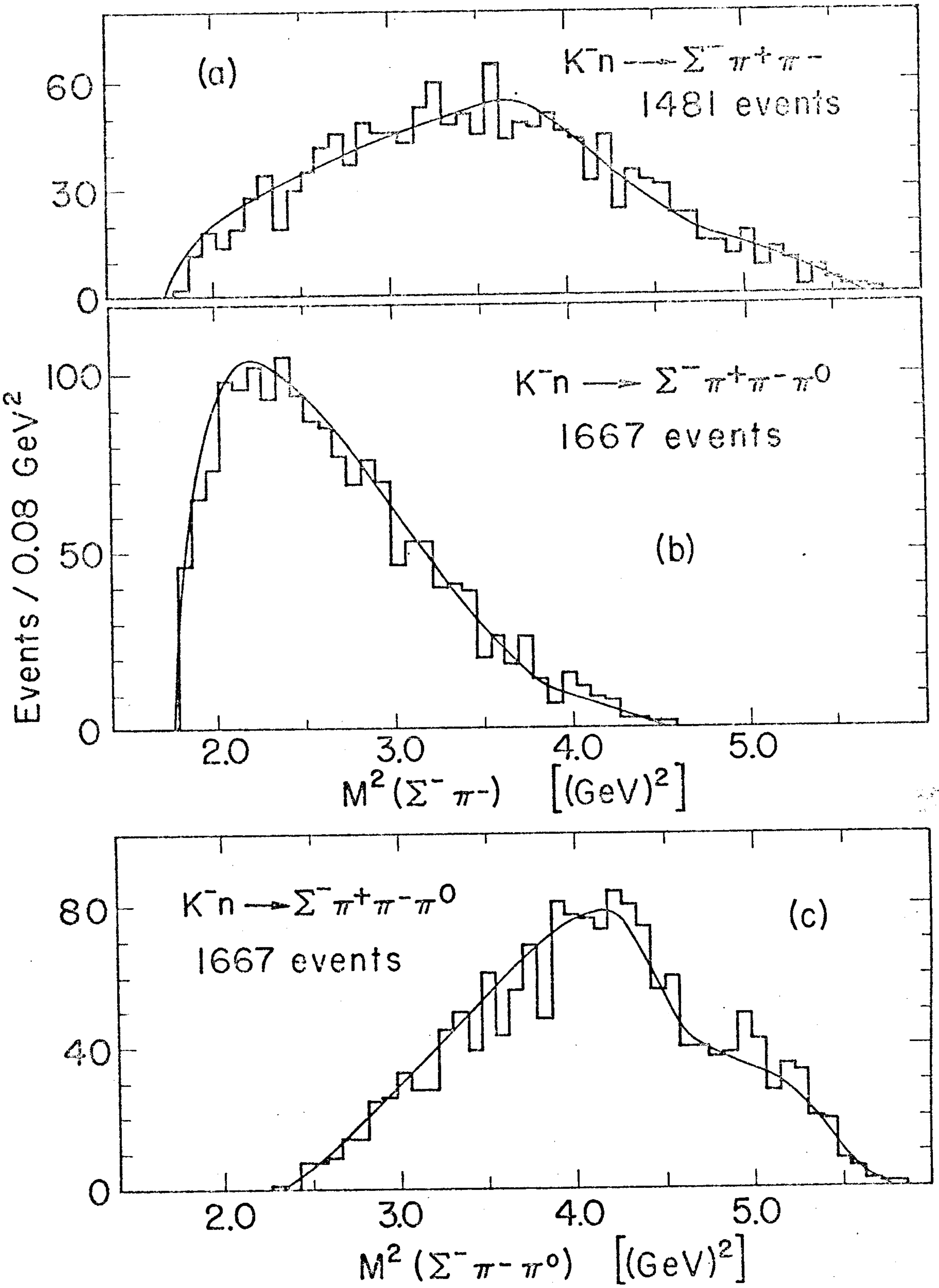

Fig. 1

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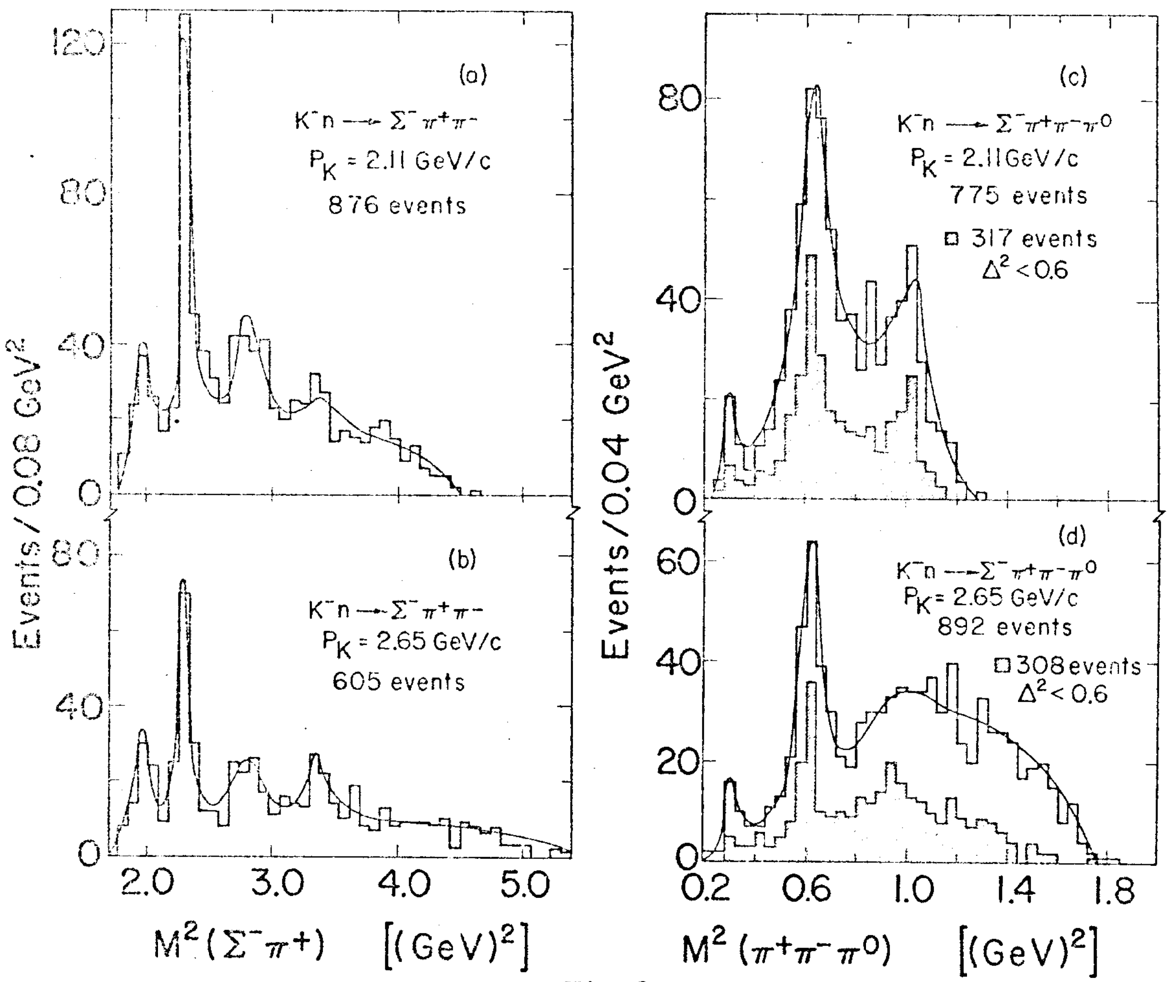

Fig. 2

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