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Analysis of π^+p and π^+n data, in the 3- to 4-GeV/c incident π^+ momentum range, shows that at present there is no convincing evidence for existence of the so-called H meson (M $\approx$ 990 MeV, suggested quantum numbers $I^GJ^P = 0^-1^+$). The enhancement observed in the neutral three-pion invariant mass distribution near 990 MeV can be attributed to the $\pi\pi\gamma$ decay mode of the η'.

This paper contains a discussion of the following points:

(A) Reported evidence in favor of and against the H meson. (See page 3.)

(B) Effects of the ρ cut. In studying an enhancement in the three-pion mass plot it is useful to analyze the $\rho\pi$ decay mode of the enhancement, since it might improve the signal-to-noise ratio and conclusions on the I-spin could easily be obtained. In the 1-GeV region of 3π mass, however, one has to be careful because the kinematics of the $\rho\pi$ system can produce a bump. (See page 4.)

(C) Possibility of appearance of the $\pi\pi\gamma$ decay mode of the η' at higher mass if a supposed π^0 is substituted for the real γ. Experiments in deuterium can produce additional mass shifts. The mass resolution in D_2 experiments is also essential in determining the size of an enhancement. (See page 7.)

(D) Reanalysis of all the data from which evidence for the H meson has been reported. To get a proper estimate of the background under the 990-MeV enhancement, a

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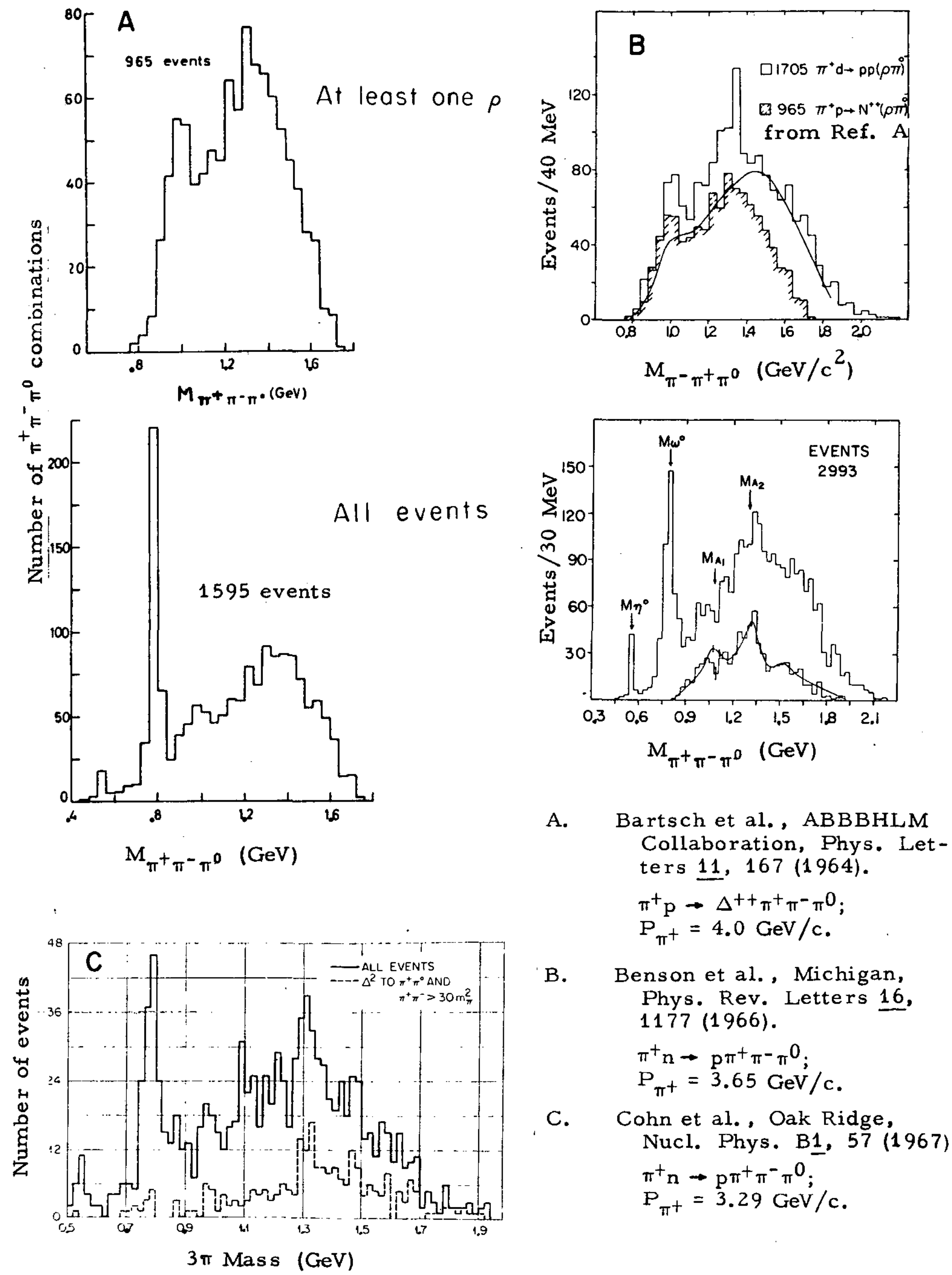

A. Bartsch et al., ABBBHLM Collaboration, Phys. Letters 11, 167 (1964).

$\pi^+ p \to \Delta^{++}\pi^+\pi^-\pi^0$;
$P_{\pi^+} = 4.0$ GeV/c.

B. Benson et al., Michigan, Phys. Rev. Letters 16, 1177 (1966).

$\pi^+ n \to p\pi^+\pi^-\pi^0$;
$P_{\pi^+} = 3.65$ GeV/c.

C. Cohn et al., Oak Ridge, Nucl. Phys. B1, 57 (1967).

$\pi^+ n \to p\pi^+\pi^-\pi^0$;
$P_{\pi^+} = 3.29$ GeV/c.

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Fig. 1. Summary of the evidence reported in favor of the H meson.

model including production of all the resonances observed in these reactions was fitted to the data. A compilation of 13 000 events of the type $\pi^+ p \to \Delta^{++}\pi^+\pi^-\pi^0$ has also been fitted in order to establish the cross section for the H enhancement. In none of the cases was the cross section for production of the H enhancement found to exceed by more than two standard deviations the value expected for η' production with subsequent decay $\eta' \to \pi^+\pi^-\gamma$. (See page 9.)

A. EVIDENCE FOR THE H MESON

The first report of an enhancement in the neutral three-pion invariant mass at $M \approx 980$ MeV was given in 1964 by a British-German collaboration,[1] two months after the discovery of the η' at $M = 960$ MeV.[2] The reaction studied was

$$\pi^+ p \to \Delta(1236)^{++}\,\pi^+\pi^-\pi^0 \qquad (1)$$

at 4.0 GeV/c incident π^+ momentum. Although the mass of the enhancement (975 ± 15 MeV) was very close to the mass of the η', the observed 120-MeV width was believed to be in disagreement with $\Gamma_{\eta'} < 12$ MeV. The cross section for the enhancement was 150 μb, or 90 events in a total sample of 1595 examples of reaction (1). Figure 1A shows these data. The $\rho\pi$ mass distribution is also shown. The authors estimated that both plots contain about 90 events in the H enhancement. At that time the authors had no evidence[3] that η' was produced in the reaction $\pi^+ p \to \Delta^{++}\eta'$.

Benson et al.[4] reported evidence for the H meson in the reaction

$$\pi^+ d \to (p_s)p\pi^+\pi^-\pi^0 \quad (p_s = \underline{\text{visible}} \text{ spectator proton}) \qquad (2)$$

at 3.65 GeV/c incident π^+ momentum. Their data are shown in Figure 1B. The mass and width quoted were 998 ± 10 MeV and 45 ± 30 MeV respectively. The cross section for the H enhancement was 75 ± 15 μb, and the cross section for $\eta' \to \pi^+\pi^-\gamma$ is estimated to be 16 ± 7 μb.[5,6] The number of events above background in the H region was 58 for both the $\pi^+\pi^-\pi^0$ and the $(\rho\pi)^0$ effective-mass plots.

In a study of reaction (2) at 3.29 GeV/c, Cohn et al.[7] also observed an enhancement in the H region. Their data are shown in Figure 1C. They estimated that the cross section for this enhancement could be as large as 50 μb (corresponding to 46 events); on the other hand, a cross section as low as 15 μb also appears compatible with these data. Therefore, the enhancement may well be due to the $\pi\pi\gamma$ decay of the η' (since π^0 and γ can hardly be distinguished in this type of experiment), for which a cross section of 11^{+6}_{-4} μb is expected.[8]

In two other experiments on reaction (1) at 3.65 and 3.2 to 3.5 GeV/c,[9,10] small enhancements were also observed in the $(\rho\pi)^0$ mass distributions near 1000 MeV. The situation as of November 1966 is summarized in Ref. 11.

More recently in a large statistics experiment, Fung et al.[12] studied reaction (1) for π^+ incident momentum in the 3- to 4-GeV/c region and did not observe an enhancement in the H region. A study of reaction (2) at 5.1 GeV/c by Armenise et al.[13] also failed to show any enhancement, although the statistics was better than in Ref. 4. At lower energies (1.8 to 2.5 GeV/c), Abolins et al.[14] do not find any evidence for the H enhancement, and quote an upper limit of 100 μb (averaged over their momentum range).

B. THE $\rho\pi$ MASS PLOT

The two upper plots of Figure 1 show the three-pion invariant-mass distributions for the data of the British-German collaboration[1] and of Benson et al.[4] when the condition that at least one dipion combination falls in the ρ band is applied to the data. In this case the H enhancement appears to be sharper; however, the shape of the background is also changed by the ρ cut applied to the data. Benson et al. first pointed out that even a smooth phase-space-distributed three-pion mass spectrum can show an enhancement at $\approx$ 1000 MeV if a ρ cut is applied.

Fung et al.[12] have made an interesting study of the effect of the ρ cut in the three-pion mass distribution. They have analyzed 3159 events of reaction (1) between 2.95 and 4.1 GeV/c, which do not indicate any enhancement in the H region for the uncut data. Figure 2 shows some of their plots. The Dalitz plots in the upper corner, taken from Rosenfeld et al.,[11] illustrate the situation. The ρ bands cover almost the whole Dalitz plot at the H mass, whereas at the A_2 mass they leave part of the area unoovered. Figure 2A (taken from Fung et al.) shows this nicely. As a function of $M_{3\pi}$ it plots the fraction of the Dalitz plot

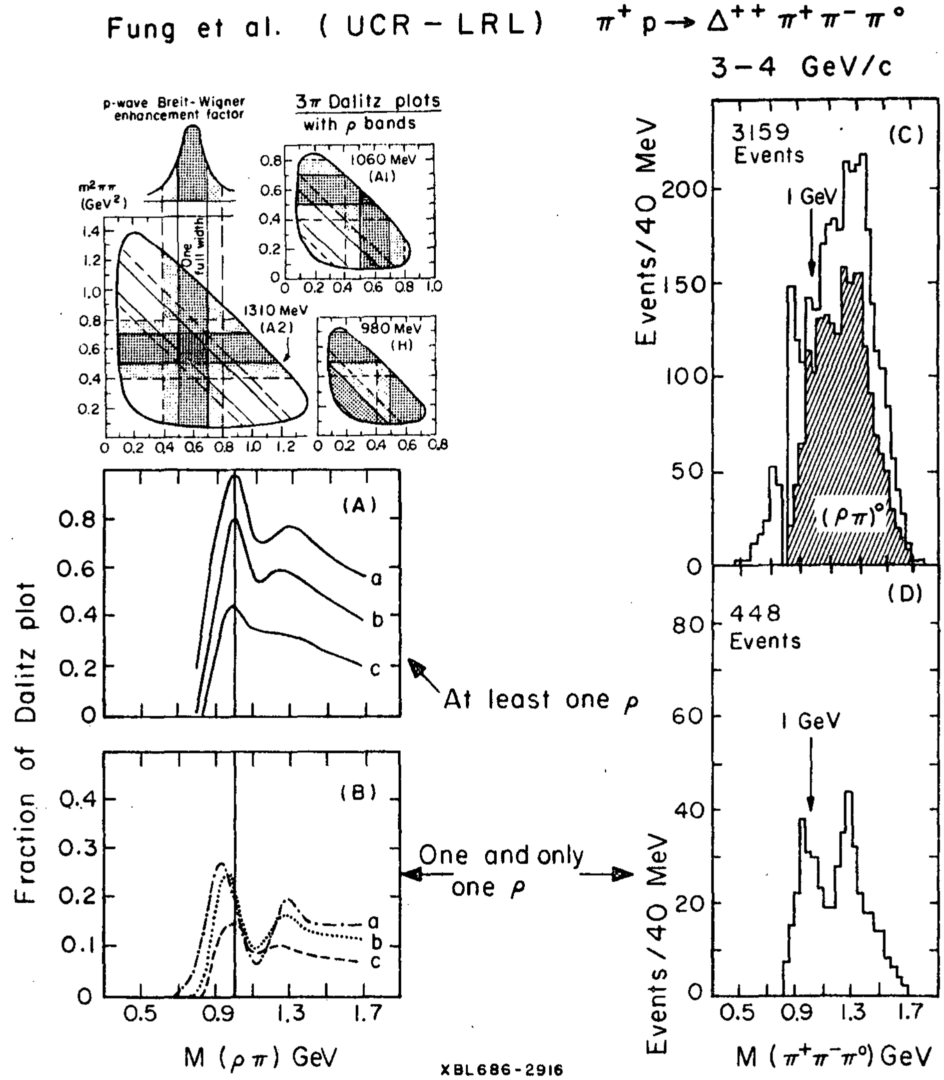

Fig. 2. The effect of the ρπ cut. Data of Fung et al. (Ref. 12). (A) shows the fraction of the three-pion Dalitz plot covered by the three ρ bands. This has been calculated using three different widths: (a) $\Delta M = \pm 120$ MeV, (b) $\Delta M = \pm 80$ MeV, (c) $\Delta M = \pm 40$ MeV (while current $\Gamma_\rho/2 \approx 50$ MeV); the bands were centered at M = 740 MeV. (B) shows the corresponding fractions of the Dalitz plot covered by only one ρ band, excluding the overlap regions of this band with the other two bands. (C) is the experimental $M(\pi^+\pi^-\pi^0)$ distribution (note that the ω band has been eliminated); the shaded area corresponds to events in the ρ bands. (D) shows the same data with the restriction that one and only one $M_{\pi\pi}$ falls into a ρ band ($\Delta M = \pm 80$ MeV).

covered by ρ bands of three different widths (labeled a, b, c). The striking feature of these curves is the peak at 1 GeV and the dip at 1.15 GeV.

Figure 2B differs from 2A in that only one band is taken, and band-overlap areas are excluded. (Figure 1A corresponds to the selection of events with at least one ρ; 1B with one and only one ρ.) Here the valley between the peaks is even deeper, and consequently the peaks are moved farther apart.

One can study the effects of ρ cuts by multiplying the curves of Figure 2A with the uncut $M_{3\pi}$ distribution. In particular, if the uncut $M_{3\pi}$ is assumed to be the three-pion phase space (which corresponds to selecting events with at least one ρ from a phase-space-distributed sample), the cut distribution will have a shoulder at $M \approx 1000$ MeV. This is illustrated by the curve in the upper part of Figure 1B, taken from Benson et al.[4] If instead of phase space one used a distribution peaking at lower $M_{3\pi}$ than phase space [e.g., due either to low momentum transfers (however, see Figure 8), or to reflections of other resonant processes], this shoulder would be enhanced (see, for example, Figures 5 and 8).

If the curves of Figure 2B were used instead (corresponding to selecting on one ρ only), a bump would appear at $M_{3\pi} \approx 1000$ MeV as shown by Benson et al.[4] and Fung et al.[12] Figure 2C shows the uncut data from the experiment of Fung et al., which do not show any enhancement at the H mass (note that the ω band has been eliminated in the plot). The shaded histogram shows the experimental distribution when the mass of at least one of the three possible ππ combinations falls into the ρ band. Figure 2D shows the experimental plot for those events which have one (and only one) ππ mass combination falling in the ρ region. This plot shows a very nice peak at the H mass, quite similar to what one gets just from multiplying the original histogram (2C) (without ρ cuts) with the weight functions of Fig. 2B. This, of course, shows nothing more than that the H Dalitz plot is nearly uniformly populated.

The conclusion from this is that under certain conditions, bumps near threshold in a ρπ mass spectrum might occur as a consequence of the particular criteria used for selecting "ρ events." It is obviously very important to take this effect into account when one tries to establish the significance of ρπ (or similar) enhancements.

C. MASS SHIFTS AND RESOLUTION

A 2.5-standard-deviation effect at the H mass was presented by one of us at the Heidelberg Conference, in the reaction $K^- n \rightarrow \Sigma^- \pi^+ \pi^- \pi^0$ at 2.1 GeV/c incident K^- momentum.[14] The experiment was performed in deuterium, and this fact produces various problems resulting in bad resolution and mass shifts. These problems have been carefully investigated in this experiment, and about 35% more events have been added, with the result that the whole H enhancement is now accounted for by the $\pi\pi\gamma$ decay mode of the η'.[15] At this incident energy it is not possible to distinguish a π^0 from a γ ray in the bubble chamber, and this problem is common to all the experiments which reported an H meson enhancement.

Figure 3A shows the three-pion invariant-mass distribution from this experiment. Figure 3B shows the plot of $M^2(\pi^+\pi^- MM)$ versus the missing mass squared (MM^2) against the $\Sigma^-\pi^+\pi^-$ system. The decay mode $\eta' \rightarrow \pi^+\pi^- \eta_n$ (by η_n or η_c we indicate η decaying into only neutral particles, or into $\pi^+ + \pi^- +$ neutral, respectively) can be detected here and, by use of the known branching ratios,[6] the expected number of events for $\eta' \rightarrow \pi^+\pi^-\gamma$ can be calculated. As can easily be seen in Figures 3A and 3B, the mass resolution for $\pi^+\pi^-\pi^0$ or $\pi^+\pi^- \eta_n$ is very bad, therefore the number of events of the type $\eta' \rightarrow \pi^+\pi^-\eta_n$ has to be counted by using the actual resolution. When this is done the H enhancement is all explained as being η'.

The curve of Figure 3A is a maximum-likelihood fit to the data.[16] The model used in the fit takes into account nonresonant background as well as production of various resonances in the final state (neglecting interferences between the various resonances). The mass required to fit the H enhancement is $M \approx 1000$ MeV (whereas $M_{\eta'} = 958$ MeV); the width is consistent with the resolution. This 40-MeV mass shift can be understood in terms of two different effects: (a) the events have been fitted with the π^0 mass instead of the γ mass (this accounts for ≈ 15 MeV); (b) in about 70% of the events the unmeasurable momentum of the spectator proton has been assumed to be $0 \pm \Delta p_i$, with Δp_i an error in the three-momentum components. This turns out to be an inadequate approximation to the Hulthén distribution, and accounts for the remaining mass shift. More details can be found in Ref. 15.

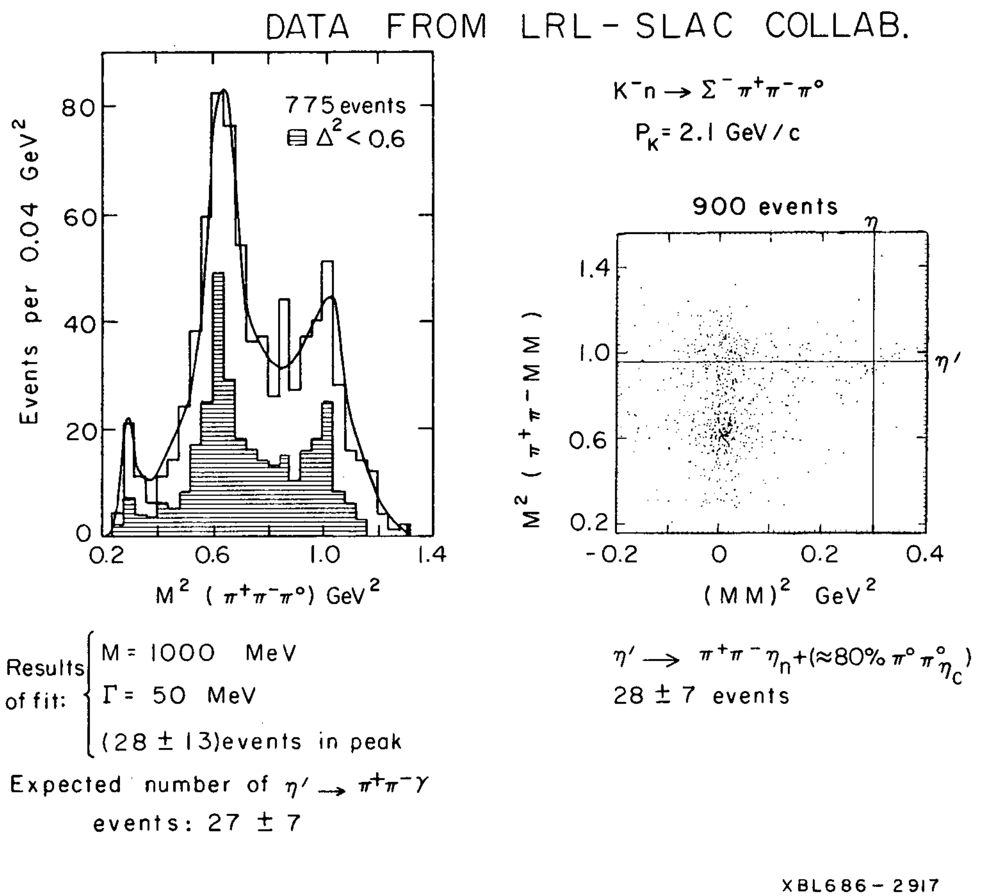

Fig. 3. Data of Barbaro-Galtieri et al.[15] on $K^-n \rightarrow \Sigma^-\pi^+\pi^-\pi^0$ at 2.1 GeV/c. The enhancement around 1000 MeV is entirely explained by $\eta \rightarrow \pi^+\pi^-\gamma$ decay.

The Argonne-Northwestern collaboration[17] has also investigated this point. In studying the reaction $K^- p \to \Lambda\pi^+\pi^-\pi^0$ at 4.1 and 5.5 GeV/c incident K^- momentum they observe the effect shown in Figure 4. The lower graphs show the three-pion invariant-mass distribution (unshaded) and the $\rho^0\pi^0$ mass plot (shaded). The same events have been also fitted with the γ mass instead of the π^0 mass, and are plotted in the upper part of Figure 4. The η' signal appears now at the correct mass, and sharper.

D. FITS TO THE H DATA

Our final task is to examine in detail the reactions in which the H has been reported, in order to see if the data still show a significant non-η' signal in the 980-MeV mass region. We do this by fitting to the data on reactions (1) and (2) a model similar to that mentioned in Section C. Data summary tapes have been made available to us by the authors of Refs. 3, 4, 9, 10, and 12. We have been able, therefore, to perform maximum-likelihood fits[16] of this model to the complete data on these experiments. In the fits, the masses, widths, and magnitudes of the various resonance contributions were varied. In order to test and display the goodness of fit, the mass distributions of all the two- and three-particle combinations in the final state, as calculated from the model, were compared with the experimental distributions. In each case, satisfactory agreement has been reached. Also inserted into the model were factors depending on various four-momentum transfers, in order to closely simulate the observed distributions of the four-momentum transfer between the incident pion and the various final-state two- and three-pion combinations. The effects of these factors on the three-pion mass distributions, however, turn out to be small. (As an example, in the insert in Figure 8 we show how this "peripheralization" modifies the phase-space distribution.)

After such a model has been fitted, one can most easily assess the kinematical effects of making ρ cuts on the 3π mass spectrum, by simply subjecting the distributions, calculated from the model, to the same cuts. Some of the results of these fits are shown and discussed below. It is hardly necessary to emphasize that a model such as the one we have used, although containing many different terms, over-simplifies grossly the actual behavior of these complicated reactions. We therefore do not attach deep physical significance to the detailed results of these fits, as

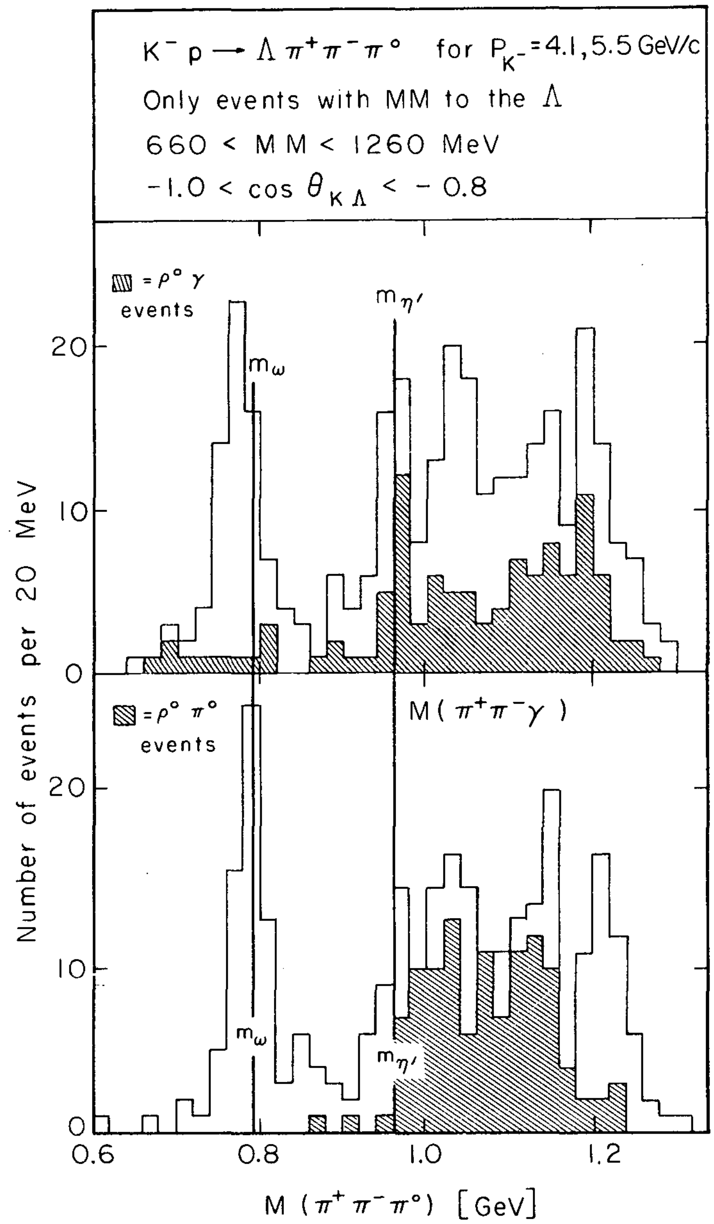

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Fig. 4. Data of the Argonne-Northwestern Collaboration,[17] showing the effect of fitting the reaction $K^- p \rightarrow \Lambda \pi^+ \pi^- \pi^0$ (γ) with a γ (upper histogram) vs. π^0 (lower histogram). Only events with 600 < MM < 1260 MeV were used, where we write $K^- + p \rightarrow \Lambda + MM$. Note in particular the effect in the $\rho^0 \gamma^0$ spectrum ($\eta' \rightarrow \pi^+ \pi^- \gamma$ is mainly $\eta' \rightarrow \rho^0 \gamma$).

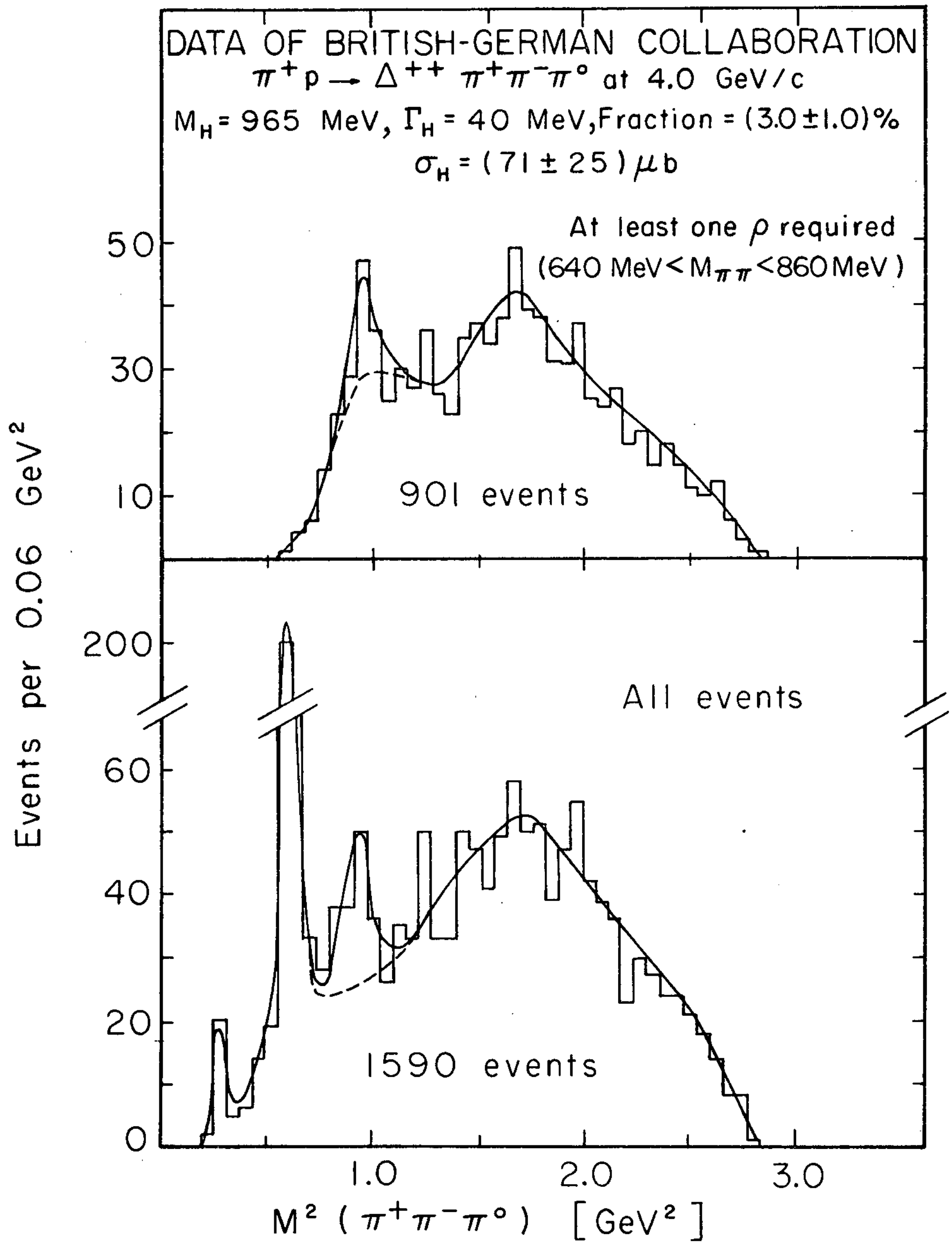

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Fig. 5. Our fit (full curve) to the data of the British-German Collaboration.[1] The dashed curves have been drawn to show the background under the H enhancement according to our fit. For the upper plot and curve, a ρ cut has been imposed (at least one dipion mass in the region $M_{\pi\pi} = 750 \pm 110$ MeV, as used by the authors of ref. 1).

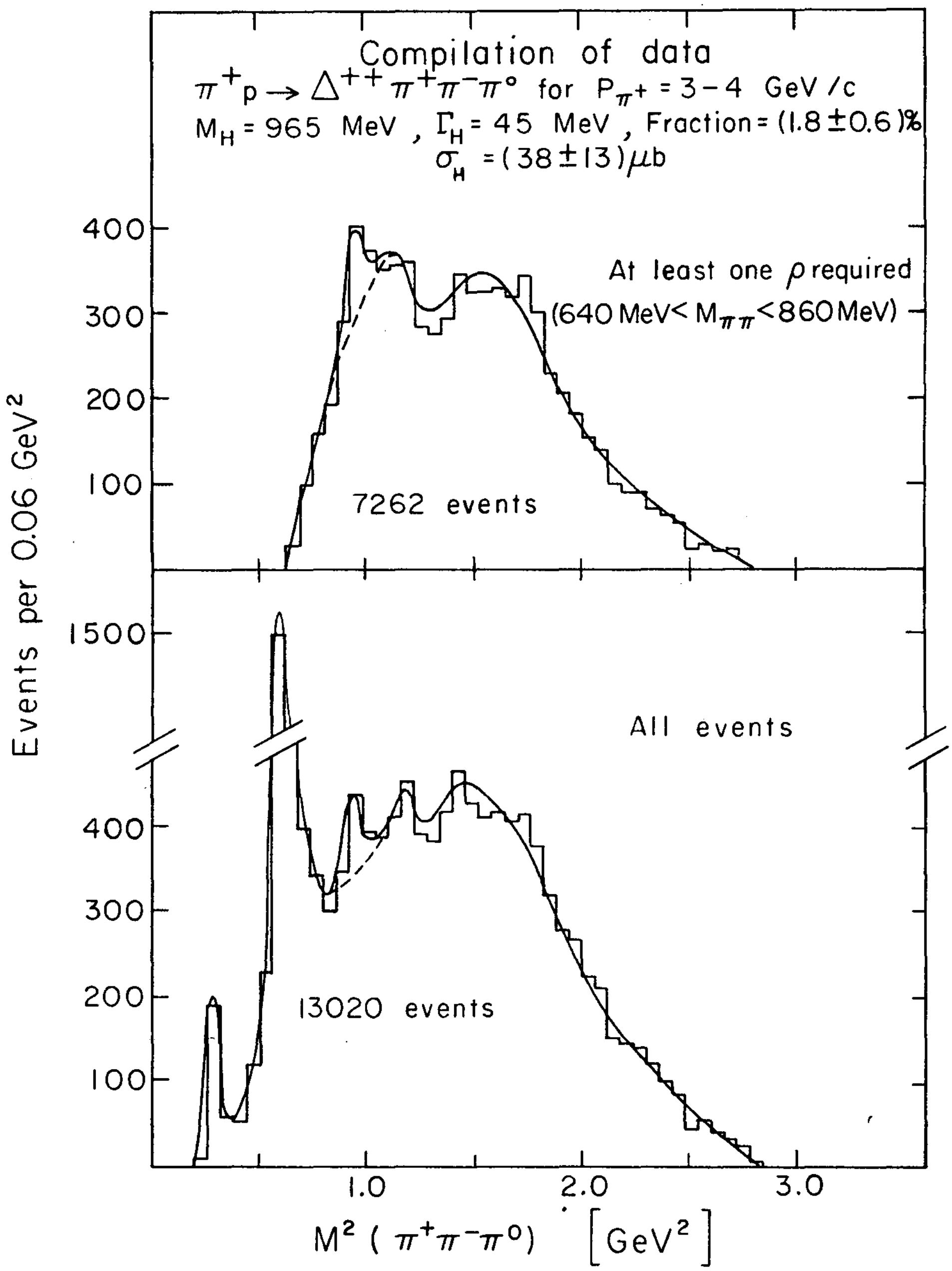

Fig. 6. Our fit (full curve) to the combined data from ref. 3, 9, 10, and 12. Dashed curves: same fit with H contribution subtracted. The histogram and curve for the cut data (at least one dipion mass in the ρ band $M_{\pi\pi}$ = 750 ± 110 MeV) is shown in the upper part of the figure.

far as production of the various resonances is concerned. All we need is a plausible model that fits the data, and thereby furnishes us with a smooth "background distribution" against which to compare an enhancement that has not otherwise been accounted for.

In Figure 5 we show the three-pion mass spectra from the data of the British-German collaboration,[1] with (upper) and without (lower histogram) a ρ cut (i.e., at least one dipion mass in the ρ resonance band). The full curves are results of our fit.[18] The fitted model includes production of η, ρ, ω, and A_2, as well as nonresonant (peripheralized phase space) background and an H enhancement. The dashed curves have been drawn to show the contribution of the H enhancement to the fit. Processes like $N^{**} \rightarrow \Delta^{++}\pi^0$ for higher nucleon isobars have also been allowed for, but were not found significantly present in the data. The mass and width of the H enhancement (including experimental resolution) were found to be M = 965 MeV and Γ = 40 MeV. If the effects discussed in Section C are taken into account, these values are consistent with mass and width of the η'. The cross section obtained for production of the H enhancement is 70 ± 25 μb, to be compared with an expected cross section for η' production, with $\eta' \rightarrow \pi^+\pi^-\gamma$ decay, of 25 ± 12 μb (as derived from the cross section for $\eta' \rightarrow \pi^+\pi^-\eta_c$, measured recently also by the British-German collaboration--Ref. 19). These two values agree to within 1.6 standard deviations (corresponding to a confidence level of 10%).

The same procedure was applied to a compilation of 13 000 events of the type of reaction (1) (including those of Figure 5) for π^+ incident momenta between 3 and 4 GeV/c. These data are from Refs. 1, 9, 10, and 12, and are shown in Figure 6. The distribution of the c.m. energies was taken into account in the fit. The best fit[18] to the data was similar to the one obtained for the subset of events of the British-German collaboration. The H bump, however, is reduced to 38 ± 13μb, or 1.8 ± 0.6% of the data (to be compared with 3 ± 1% for the British-German collaboration data). Assuming that this signal is due to η', we can calculate the total cross section $\sigma(\eta')$ for η' production from the known branching ratios[6] in order to be able to compare it with $\sigma(\eta')$ as derived from the $\pi\pi\eta$ decay mode. This comparison is shown in Figure 7, where all the measured cross sections above 2 GeV/c for $\pi^+p \rightarrow \Delta^{++}\eta'$ production are shown along with those for $\pi^+p \rightarrow \Delta^{++}\eta$ and $\pi^+p \rightarrow \Delta^{++}\omega$.[20]

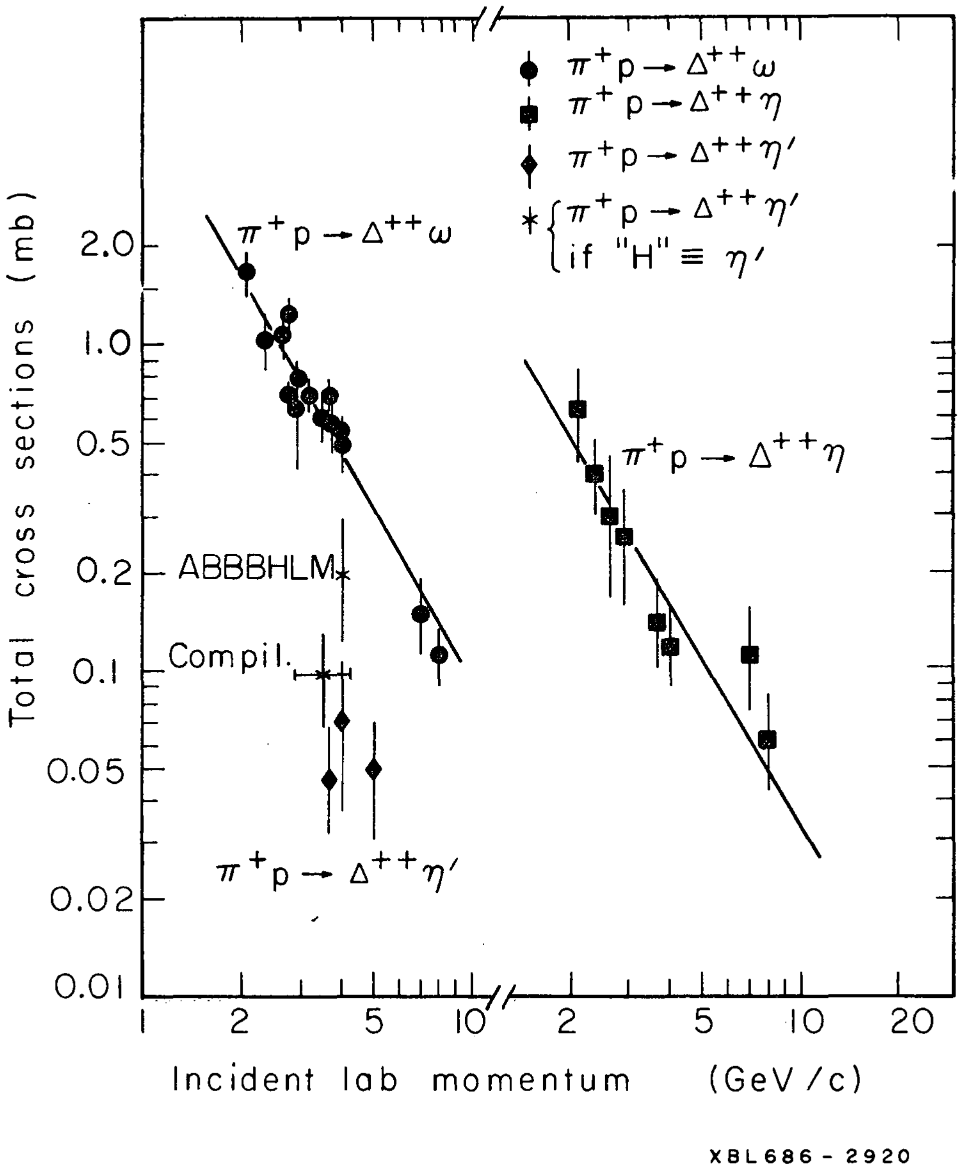

Fig. 7. Total cross sections for the reactions $\pi^+p \to \Delta^{++}(1236)$+meson as a function of incident π^+ momentum.[20] The straight lines are hand drawn through the points. Crosses indicate total cross sections for η' production if the "H" signal were $\eta' \to \pi^+\pi^-\gamma$. The η' cross sections (◆) were obtained through the measurement of the partial cross section for $\eta' \to \pi\pi\eta$.

(Unfortunately the $\pi\pi\eta$ decay mode for the η' has not been measured in all the experiments used in our compilation, so that a direct comparison cannot be made for this sample.) Both the η and ω production cross sections seem to obey a linear law in this log-log plot, and it is reasonable to expect that the η' cross section follows a similar behavior. The η' cross section obtained from the compiled data is then seen to be in perfect agreement with the other three measured cross sections for η' production.

In Figure 8, the 3π and $\rho\pi$ mass plots of Benson et al.[4] from reaction (2) at 3.65 GeV/c are shown, together with the distributions obtained from our fit.[18] The spread in the incident c.m. momentum in the π^+n rest system, due to the Fermi motion in the deuteron, has been taken into account. We allowed for the presence of various higher nucleon resonances in the data, and we also found it necessary to add an $A_{1.5}$ (M = 1160 MeV, Γ = 120 MeV including resolution) production term[21] in order to fit the shoulder in the three-pion mass spectrum that is apparent in the data at 1160 MeV. For the H enhancement, values of M = 998 MeV and Γ = 40 MeV (resolution not subtracted) were obtained. We were not able to study in detail the possible mass shift and resolution effects (cf. Section C) for this experiment, since these depend on many experimental details. Realizing the difficulties peculiar to analyzing reactions on deuterium, we believe that the possibility cannot be excluded that the above values for mass and width of the observed H enhancement are consistent with mass and width of the η'.

The production cross section for the H enhancement that we obtain on the basis of this fit is 41 ± 18 μb. Under the assumption that all the observed H signal is due to $\eta' \to \pi^+\pi^-\gamma$, we obtain[6] from this a $\pi^+n \to p\eta'$ cross section of 117 ± 53 μb. This value is compared in Figure 9 with the other known values for the η' production cross section;[22] we conclude that there is reasonable agreement between them. In particular, the value of 46 ± 20 μb obtained in the same 3.65-GeV/c π^+d experiment[4,5] from the observation of the $\eta' \to \pi\pi\eta$ mode agrees with the value of 117 ± 53 μb from the H enhancement to within better than 1.5 standard deviations (confidence level > 15%).

From studies of the Dalitz plot[1,4] and of the decay angular distributions[4] of the events in the H region, it has been suggested that J^P of the three-pion states in the enhancement is most likely to be 1^+, 2^-, $\cdots$. In particular,

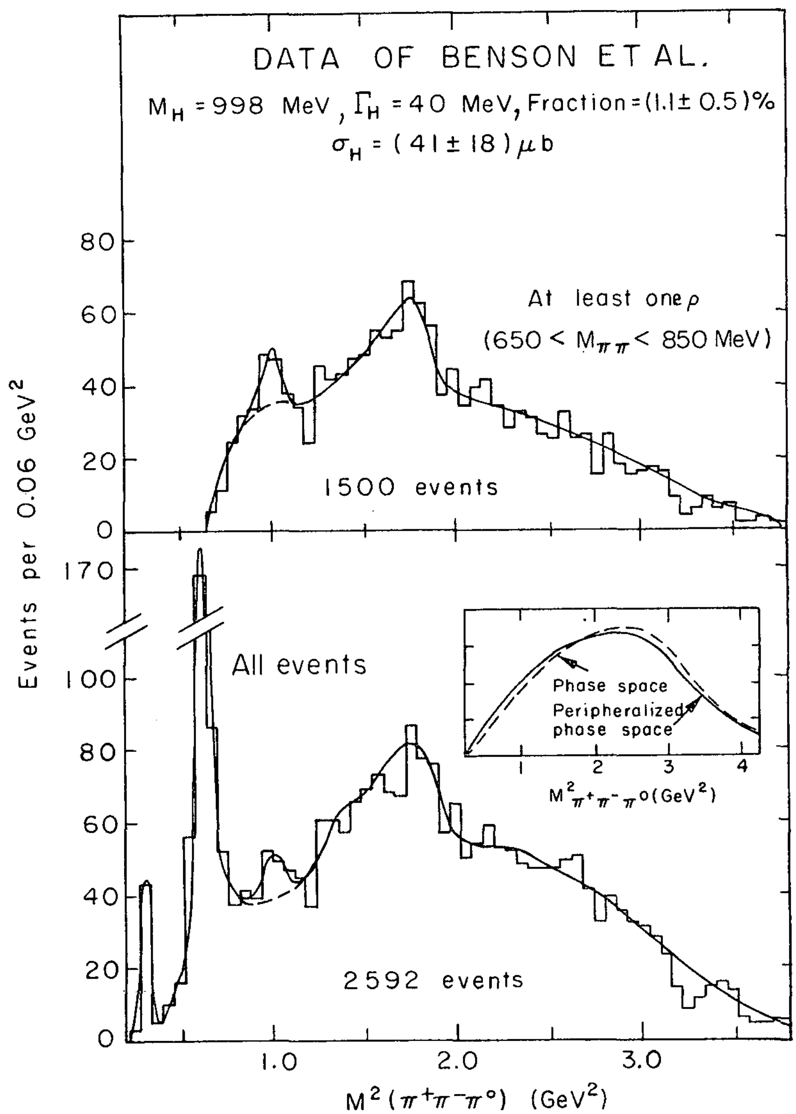

Fig. 8. Our fit (full curve) to the data of Benson et al.[4] The dashed curves show the background under the H enhancement according to our fit. The upper plot and curves refer to events which contain at least one dipion mass in the ρ band $M_{\pi\pi}$ = 750 ± 100 MeV (as used by Benson et al.).
The insert shows the three-pion mass distribution according to phase space (dashed curve), and to peripheralized phase space (full curve) that includes momentum-transfer-dependent factors, as explained in the text.

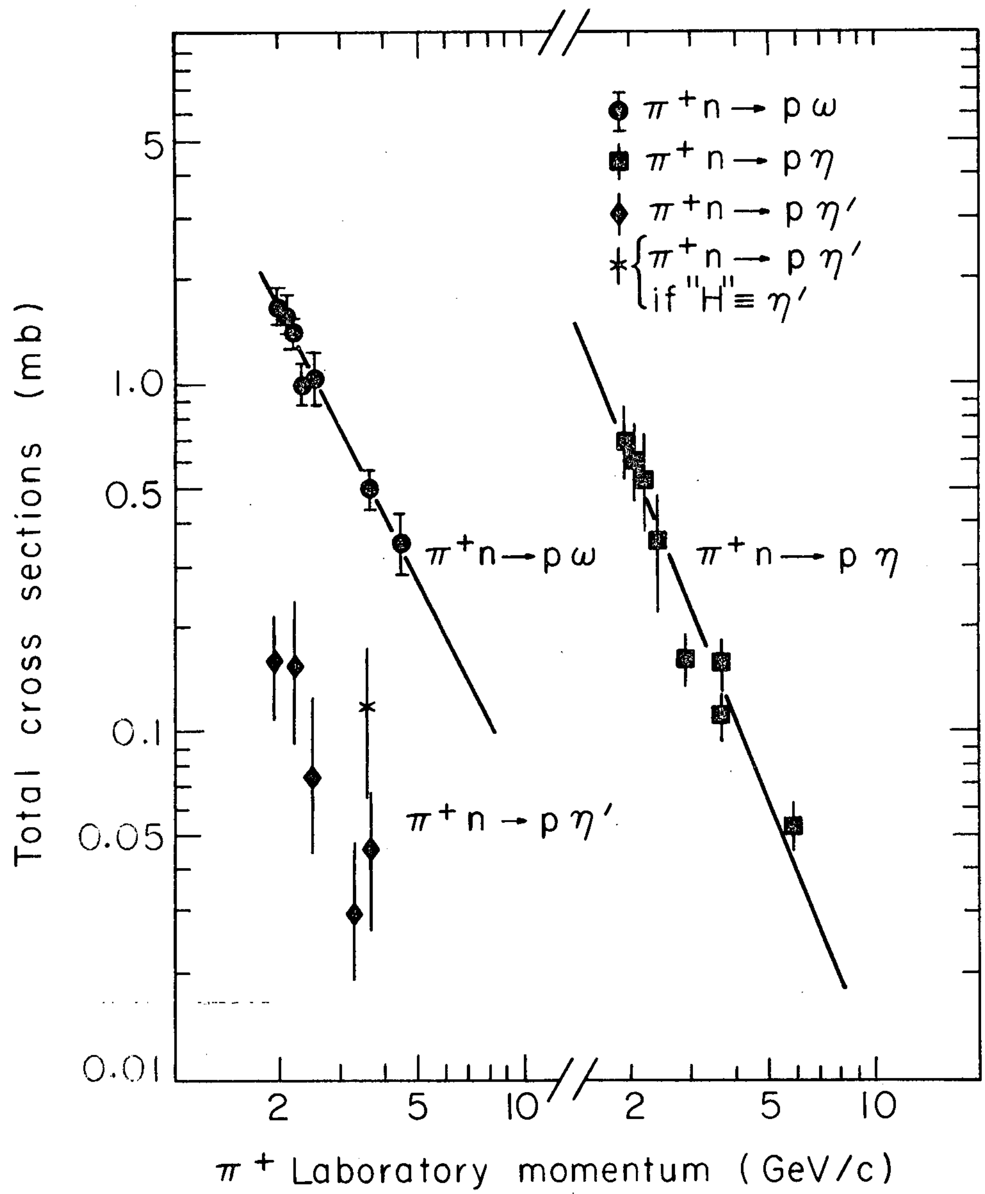

Fig. 9. Total cross sections for the reactions $\pi^+ n \rightarrow p +$ + meson as a function of incident π^+ momentum.[22] The straight lines are hand drawn through the points. ⚹ indicates the total cross section for η' production if the "H" enhancement seen by Benson et al.[4] were due to $\eta' \rightarrow \pi^+\pi^-\gamma$. The η' cross sections (◆) were obtained through measurement of the partial cross section for $\eta' \rightarrow \pi\pi\eta$.

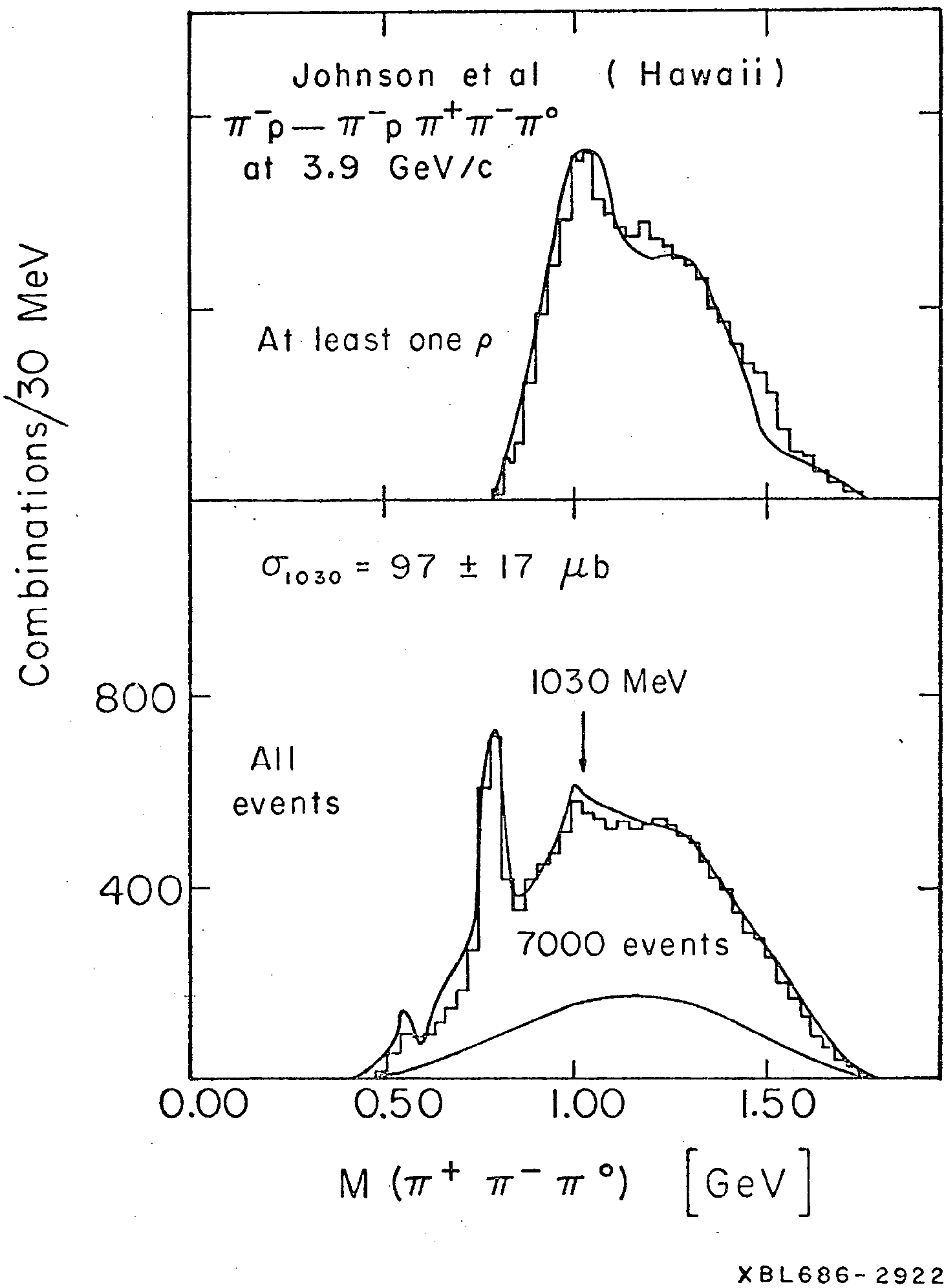

Fig. 10. Data and fit of Johnson et al.[23] for the reaction $\pi^- p \rightarrow \pi^- p \pi^+ \pi^- \pi^0$ at 3.9 GeV/c. The enhancement centered at ≈ 1030 MeV is being investigated to ascertain its possible connection with the "H" enhancement.

$J^P = 0^-$ appeared unlikely because the density distribution did not seem to vanish along all three medians of the Dalitz plot (i.e., along the lines $M^2_{\pi^+\pi^-} = M^2_{\pi^-\pi^0}$, $M^2_{\pi^-\pi^0} = M^2_{\pi^0\pi^+}$ and $M^2_{\pi^0\pi^+} = M^2_{\pi^+\pi^-}$ as required for an $I = 0$, $J^P = 0^-$ three-pion state), and also because the events in the H region showed a nonisotropic decay angular distribution with respect to the beam direction and to the normal of the production plane. For a $\pi^+\pi^-\gamma$ Dalitz plot, however, the first argument against $J^P = 0^-$ is no longer valid. From examination of the Dalitz plots of the experiments discussed here, we conclude that the distribution expected for $\eta' \to \pi^+\pi^-\gamma$ decay, with the $\pi^+\pi^-$ system being ρ^0, is compatible with the data in view of the large background that our fits predict under the H peak. Because of this large background we also believe $J^P = 0^-$ is perfectly compatible with the observed (weak) anisotropies in the decay angular distributions.

We know of no other published evidence for the H enhancement, although Johnson et al.[23] report an enhancement in the same general region in the reaction $\pi^-p \to \pi^-p\,\pi^+\pi^-\pi^0$ at 3.9 GeV/c. Their data are shown in Figure 10. The enhancement in question is about 60 MeV wide, centered at ≈ 1030 MeV, the quoted cross section being $\sigma = 97 \pm 17$ μb; however, a cross section as low as 50 μb seems to be compatible with the data. The η' cross section for this same experiment has not been measured yet, although there is an indication that it is considerably smaller than the signal seen here. These authors are now looking into the problem of the mass shift and investigating the possibility that this signal is due to neutral A_1 production, since its location seems to be closer to the A_1 mass than to the η'.

In conclusion, it appears that the original evidence for the H meson of the British-German collaboration, which according to our analysis and with our present knowledge on η' branching ratios seems to be only a 1.6 standard deviation effect, has not been supported by the additional data available now at similar energies. In deuterium experiments, the H has shown up in only one experiment and has failed to appear in others; furthermore, the statistical significance is not large. In our opinion this does not, at present, constitute sufficient evidence for an H resonance.

The discrepancy between our evaluation of the cross sections for production of the H enhancement, and those in the literature, is due to our different treatment of the background. In our fits to the data we included, apart from the resonances in the three-pion system, various other possible resonance production processes, in order to get a good fit to the overall reaction, and thereby a more reliable (though probably conservative) background estimation. This was possible because we used a complicated computer program[16] and a larger computer capacity than was available to the authors of the original papers on the H meson at the time of their analysis.

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get $\sigma(\eta') = 46 \pm 20\,\mu b$. (By η_n or η_c we indicate η decaying into only neutral particles, or into $\pi^+ + \pi^- +$ neutral, respectively.)

6. The present best estimate of the η' branching ratios is $\Gamma(\eta' \to \pi\pi\eta)/\Gamma_{total} = 0.65 \pm 0.04$, $\Gamma(\eta' \to \pi^+\pi^-\gamma)/\Gamma_{total} = 0.35 \mp 0.04$. All η' decay seems to be accounted for by these two modes. Alan Rittenberg (Lawrence Radiation Laboratory), private communication. We also use $\Gamma(\eta \to \pi^+\pi^-$ neutral$/\eta \to$ total$) = 0.29$.

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18. Results of the fits:

(a) For the $\pi^+p \to \Delta^{++}\pi^+\pi^-\pi^0$ data (Ref. 1) at 4 GeV/c (Figure 5): $\Delta^{++}\eta$ (1.4%), $\Delta^{++}\omega$ (21%), $\Delta^{++}H$[M = 965 MeV, Γ = 40 MeV, (3.0 ± 1.0)%], $\Delta^{++}A_2$ (7%), $\Delta^{++}\rho^+\pi^-$ (11%), $\Delta^{++}\rho^0\pi^0$ (9%), peripheralized phase space (48%). The Δ^{++} events were selected in the band 1.13 to 1.33 GeV; events in which both $p\pi^+$ combinations were in the band were included.

(b) For the $\pi^+p \to \Delta^{++}\pi^+\pi^-\pi^0$ data, compilation in the 3- to 4-GeV/c region (Figure 6): $\Delta^{++}\eta$ (1.5%), $\Delta^{++}\omega$ (25%), $\Delta^{++}H$ [M = 965 MeV, Γ = 45 MeV, (1.8 ± 0.6)%], $\Delta^{++}A_1^0$ (0.5%), $\Delta^{++}A_2$ (1%), $\Delta^{++}\rho^+\pi^-$ (14%), $\Delta^{++}\rho^0\pi^0$(9%), $N^{*+}(1690)\pi^+\pi^0$(2%), four-body phase space (45%). For the Δ^{++} selection, see under (a), above.

(c) For the $\pi^+n \to p\pi^+\pi^-\pi^0$ data near 3.65 GeV/c (Ref. 4) (Figure 8): $p\eta$ (1.5%), $p\omega$ (16%), pA_2(6.6%), pH[M = 998 MeV, Γ = 40 MeV, (1.1 ± 0.5) %], $pA_{1.5}^0$ (3.8%), $\Delta^+(1236)$ ρ^0 (1.8%), $\Delta^{++}(1236)\pi^-\pi^0$(8.8%), $\Delta^0(1236)\pi^+\pi^0$ (1.5%), $p\pi^-\rho^+$(9.9%), $p\pi^+\rho^-$(4.2%), $p\pi^-\rho^0$ (10%), $N^{*0}(1690)\pi^+$ (8.3%), $N^{*+}(1690)\pi^0$(6.0%), $N^{*0}(1520)\pi^+$(6.0%), $N^{*+}(1520)\pi^0$ (4.0%), $N^{*+}(2190)\pi^0$ (2.7%), $\Delta^0(1920)\pi^+$(7.8%), phase space (0%). For the ω contribution, we used a Breit-Wigner resonance curve, folded with a resolution function similar to the one we had observed in an experiment using a deuterium bubble chamber at 2.1 GeV/c (Ref. 15). The resulting function had a full width at half maximum of 44 MeV.

For the H enhancement a S-wave Breit-Wigner form was used. This is usually a reasonable approximation to the resolution functions in bubble chamber experiments. The quoted errors in the amount of H present in these three fits include all the uncertainties of the multiparameter fits, therefore are larger than the statistical errors in the one-dimensional histograms. We give these results in order to allow the reader to check our calculations, and not because we believe that they necessarily have much physical significance. Although preference for small momentum transfers in the production of the various resonances has been taken into account (see text), all interferences between the different contributions, as well as anisotropies of the decay angular distributions of the resonances with respect to the incoming beam direction, have been neglected.

19. The cross section for the H enhancement has been calculated by using as normalization the total cross section for $\pi^+ p \to p\pi^+\pi^+\pi^-\pi^0$ of 3.43 mb for 2363 events (Ref. 3). The cross section for $\eta' \to \pi^+\pi^-\eta_c$ was measured and found to be 8.6 ± 3.5 μb. Using the known branching ratios (Ref. 6), we derive the total cross section $\sigma(\eta') = 71 \pm 32$ μb, and $\sigma(\eta' \to \pi^+\pi^-\gamma) = 25 \pm 12$ μb. Aachen-Berlin-Bonn-Hamburg-München Collaboration, Nuovo Cimento 44A, 530 (1966); and G. Wolf (SLAC), private communication.

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