Title

SEARCH FOR A 2 n- RESONANCE NEAR 730 MeV IN n+ d INTERACTIONS

Authors

Smith, Gerald A.
Manning, Robert J.

Publication Date

1967-12-04

University of California

Ernest O. Lawrence Radiation Laboratory

SEARCH FOR A $2\pi^0$ RESONANCE NEAR 730 MeV IN π^+d INTERACTIONS

Gerald A. Smith and Robert J. Manning

February 14, 1968

Berkeley, California

Submitted to Physical Review

UCRL-17917 Rev.
Preprint

UNIVERSITY OF CALIFORNIA
Lawrence Radiation Laboratory
Berkeley, California

AEC Contract No. W-7405-eng-48

SEARCH FOR A $2\pi^0$ RESONANCE NEAR 730 MeV IN π^+d INTERACTIONS

Gerald A. Smith and Robert J. Manning

February 14, 1968

SEARCH FOR A $2\pi^0$ RESONANCE NEAR 730 MeV IN π^+d INTERACTIONS*

Gerald A. Smith† and Robert J. Manning

Lawrence Radiation Laboratory
University of California
Berkeley, California

February 14, 1968

ABSTRACT

In an analysis of 229 000 pictures of π^+ at incident momenta of 1.1 to 2.3 GeV/c in the deuterium-filled 72-inch bubble chamber, we have identified 8386 examples of the reaction $\pi^+d \rightarrow pp$ + neutrals. An application of the impulse approximation gives 4965 events of the type $\pi^+n \rightarrow p$ + neutrals. At a small momentum transfer (≤ 0.2 and 0.08 GeV/c^2) to the neutrals system, we find no direct evidence for an enhancement near the reported position of the ϵ^0, ≈ 730 MeV. A detailed subtraction of $3\pi^0$ and $N^*(1238)$ background based on cross sections from other experiments results in a $2\pi^0$ mass spectrum, which is found to be in agreement with the direct experimental results of Corbett et al. (in shape only) and with the prediction of Malamud and Schlein (in shape and magnitude). The latter is based on an analysis of the ρ decay asymmetry. Consequently, we interpret our results to be consistent with the existence of the ϵ^0, the parameters for which result from the analysis by Malamud and Schlein.

Numerous authors have reported their interpretation of the ρ^0 decay asymmetry.[1] These reports generally have in common the inclusion of an isospin-0 S-wave π-π background amplitude, and for the most part conclude that the phase shift, δ_0^0, passes through or near 90 deg at ≈ 730 MeV. Due to the off-mass-shell nature of the π-π scattering, corrections of an approximate nature have been applied, resulting in some variation among the various analyses in both the position and width of this "resonant" amplitude. Subsequently, several experimenters have attempted to find the $2\pi^0$ decay mode of this particle, commonly referred to as the ϵ^0, in a direct manner by measuring the neutrals spectrum in the reaction $\pi^- p \rightarrow n$ + neutrals.[1] The virtue of such experiments lies in that the large isospin-1 π-π amplitude, associated with the ρ meson, is not present in the $2\pi^0$ system. Except for the experiment by Feldman et al., no evidence has been reported[2] for the existence of the process $\pi^- p \rightarrow n\epsilon^0$, $\epsilon^0 \rightarrow 2\pi^0$. This paper presents our measurement of the neutrals spectrum and relates it to previous experiments.

In an analysis of 229 000 pictures of π^+ at incident momenta of 1.1 to 2.3 GeV/c in the deuterium-filled 72-inch bubble chamber, we have identified 8386 examples of the reaction $\pi^+ d \rightarrow pp$ + neutrals (2 prongs) and 11 173 $pp\pi^+\pi^-\pi^0(\gamma)$ (4 prongs). In order to reduce background, only two-prong events with both tracks having ionization clearly twice minimum or greater were recorded, whereas for the four-prong events only one track was required to satisfy this criterion. Applying the impulse approximation to the $\pi^+ d$ collision, we have selected events in which the laboratory-system momentum of the proton spectator (the slower of the two protons) is less than 300 MeV/c. In Fig. 1(a) we have plotted the spectator momentum distribution for the two-prong sample, comparing it with the Fourier transform of the deuteron wave function that is applicable if the impulse approximation is valid. The comparison is generally good below approximately 300 MeV/c.[3] Consequently, we hereafter interpret such events as examples of free $\pi^+ n$ scattering within the deuteron with negligible final-state interactions. In Fig. 1(b) we show the mass distribution of the neutrals + proton (nonspectator) system, which in the impulse approximation is the $\pi^+ n$ c.m. energy spectrum. The height of this distribution is proportional to the product of the track length in the chamber and the cross section, and the distribution itself exhibits the usual smearing due to the Fermi motion of the deuteron target. The selection on the spectator momentum, as well as requiring that $1.3 \leq$ "p_{lab}"$(\pi^+) \leq 2.3$ GeV/c,[4] resulted in a sample of 4956 events.

In order to establish the amount of neutral ω^0 decay in our sample, we have independently fitted the four-prong events to a mixture of single-particle (η^0 and ω^0) production plus three-pion phase-space background, and then applied the known branching ratio for $\omega^0 \rightarrow \pi^0 \gamma$ compared with $\pi^+\pi^-\pi^0$.[5] An extremely useful by-product of this analysis is a measure of the neutral-to-charged branching ratio of the η^0, which gives a precise check on scanning and measuring biases, particularly important in view of the different scanning criteria used for the two- and four-prong events. This is accomplished by also fitting the neutral spectrum to η^0, ω^0 production plus $2\pi^0$ phase space. The results of these fits, in terms of the branching ratio of all neutrals to the sum of all neutrals plus $\pi^+\pi^-\pi^0$ and $\pi^+\pi^-\gamma$ for η^0 decay, are (a) $|t(\text{neutrals})| < 0.6\ (\text{GeV/c})^2$, 70.3 ± 2.6 %, and (b) $|t(\text{neutrals})| < 0.2\ (\text{GeV/c})^2$, 79.1 ± 4.0 %. These compare favorably with the latest value quoted by Rosenfeld et al., 73.3 %.[5] Although the $3\pi^0$ background may be as much as 40% of the total $2\pi^0$ and $3\pi^0$ cross section, the overall agreement of the branching ratios indicate that the amount of resonance is not very sensitive to the background assumptions.[6] We have made momentum-transfer selections in the region of 730 MeV by restricting the neutrals c.m. angle, the value of which for fixed momentum transfer depends on the c.m. energy. This is done in order to facilitate our fitting procedure, since phase space is independent of selections in the c.m. angle.

In Fig. 2 we show the neutral-mass-squared spectrum for momentum transfers to the neutrals system near 730 MeV of less than 0.20 and 0.08 $(\mathrm{GeV}/c)^2$. The solid curves represent the best fit to η^0, ω^0, and $2\pi^0$ phase space. The shaded events have been subtracted for $\omega^0 \to \pi^0\gamma$ by the method discussed previously, where in the subtraction we have folded together the known width of the ω^0, 12 MeV, and our experimental resolution, ≈ 26 MeV. Considering only the unshaded events, we observe no statistically significant enhancement in the region of 730 MeV for $|t| < 0.20$ $(\mathrm{GeV}/c)^2$. However, for $|t| < 0.08$ $(\mathrm{GeV}/c)^2$ we observe, after subtraction, an enhancement near 0.6 $(\mathrm{GeV})^2$. Since the $3\pi^0$ background (dotted curve) is rising through this region, and $N^*(1238)$ production undoubtedly distorts the spectrum somewhat, this enhancement cannot immediately be inferred as originating in the $2\pi^0$ system. This aspect of the analysis is considered in detail in the following comparison of our data with those of previous experiments.

Our average beam momentum, ≈ 1.8 GeV/c, does not always coincide with that of the other experiments, and appropriate allowances should therefore be made in comparing our results with others. Durand and Chiu, in an analysis at 3 GeV/c and $|t| < 0.2$ $(\mathrm{GeV}/c)^2$, state that the $\epsilon^0:\rho^0$ production ratio should be about 0.05, including only the $\epsilon^0 \to 2\pi^0$ mode.[7] Using Jacob's ρ^0 cross section of 1.6 ± 0.1 mb at 2.05 GeV/c[8] and an upper-limit estimate of ≈ 50 μb for $\epsilon^0 \to 2\pi^0$ production from this experiment, we place an upper limit of ≈ 0.03 on this ratio, somewhat less than that predicted. However, this difference could be explained in terms of a very modest energy dependence for ϵ^0 production. Malamud and Schlein predict the shape and magnitude of the $2\pi^0$ mass spectrum, indicated as the dashed curve in Fig. 2(b).[9] This is based on an analysis of data from 2.1 to 3.2 GeV/c and $|t| < 0.175$ $(\mathrm{GeV}/c)^2$.

The agreement of our data and the curve in the region ≈ 0.38 to $0.55\ (\text{GeV})^2$, particularly in absolute magnitude, strongly suggests that in this region both $3\pi^0$ and N^* background are negligibly small, whereas the lack of agreement above $0.55\ (\text{GeV})^2$ is likely explained in terms of this form of background. This conclusion appears to be basically sound, as is shown in the following discussion.

We have attempted to reduce our neutrals spectrum to a $2\pi^0$ sample, based on a subtraction of $3\pi^0$ and N^* phase-space distributions. In order to do this in an absolute way, we assume the spectrum is composed of only $n2\pi^0$ and $n3\pi^0$ events, and that the latter are 40% of the total.[10] Furthermore, we assume that the $n2\pi^0$ sample is made up of 40% N^*'s, based on the results of Corbett et al.[11] In Fig. 3 we show (solid points) the resultant distribution after subtraction of $3\pi^0$ and N^* background in these amounts. The solid histogram is the unsubtracted sample; however, the η^0 and ω^0 contributions have been removed.[12] The sample has been further restricted by the selection $\cos_{c.m.}$ (neutrals) > 0.8 and $1.8 \leq p_{lab}(\pi^+) \leq 2.3$ GeV/c, in order that we may compare directly with the data of Corbett et al. (open points). Whereas our $2\pi^0$ spectrum agrees quite well with that of Corbett et al. in shape, we have had to adjust the Corbett et al. data upward by a factor of 2.96 in absolute magnitude (μb/100 MeV) so that the total cross sections are in agreement. The source of this difference is currently unknown.[13] It is important to note that the predictions by Malamud and Schlein (solid curve) agree quite well with our data, both in magnitude and in shape.[14] Consequently, we conclude that our spectrum is consistent with that resulting from the analysis by Malamud and Schlein, and with the Corbett et al. data (in shape only). Lastly, we note that Corbett et al. previously concluded that their data show no evidence for any of the relatively narrow (30 to 100 MeV) S-wave resonances that have been proposed. However, the more recent work of Malamud and Schlein with a resonance at 730 MeV and width 150 MeV appears quite compatible with the data.

In closing, we briefly discuss two possible complications in any experiment analyzing the reaction $\pi^+ d \rightarrow pp$ + neutrals. These complications are due to (a) possible proton contamination in the π^+ beam, and (b) the Pauli exclusion of certain angular momentum states of the final diproton system, particularly at low momentum transfer to this system. Gezelter et al. have suggested that the interpretation of real p+d events in terms of the above reaction leads to a broad enhancement in the neutrals spectrum in the region $\approx 0.70\ (\mathrm{GeV})^2$, due to the presence of N^* production in the pn collision.[15] Based on an identical analysis of two-prong events in 15 400 pictures of incident protons taken in this experiment, an upper-limit estimate of 2% proton contamination would lead to an excess of approximately 2 μb/0.03 $(\mathrm{GeV})^2$ per bin in Fig. 2(b). Although this is a nonnegligible effect, it does not alter our conclusions on the agreement of our data with those of Corbett et al. and with the prediction by Malamud and Schlein. The Pauli exclusion effect may be qualitatively understood in the limit of zero momentum transfer. In this case, the final-state protons have the same orbital angular momentum as the deuteron ($\ell = 0$), and consequently the non-spin-flip amplitude ($J = 1$) is forbidden. This reduces the cross section increasingly as one approaches the zero-momentum-transfer limit. Benson has considered this effect for π-exchange and shows that the reduction of cross section averaged over $|t| < 0.08\ (\mathrm{GeV})^2$ is approximately 10%.[16] This is well within our statistical uncertainties, and therefore, as in (a) above, has little or no influence on our conclusions.

The authors wish to thank Dr. Maris Abolins, Dr. Janos Kirz, and Dr. Stanley Wojcicki for their help during the bubble chamber run and for discussions during the course of analysis. One of us (GAS) is indebted to Professor Luis Alvarez for the courtesy extended to him as a visitor in the Alvarez group during the latter stages of this work. Lastly, we thank Professor P. E. Schlein for many useful discussions and communicating his unpublished results to us.

References and Footnotes

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

†Presently at Physics Dept., Michigan State University, E. Lansing, Michigan.

1. For a comprehensive source of references to previous work on this subject, see J. P. Baton and J. Regnier, Nuovo Cimento, 36, 1149 (1965); I. F. Corbett, C. J. S. Damerell, N. Middlemas, D. Newton, A. B. Clegg, and W. S. C. Williams, Phys. Rev. 156, 1451 (1967); A. Buhler-Broglin, P. Dalpiaz, T. Massam, F. L. Navarria, M. A. Schneegans, F. Zetti, and Z. Zichichi, Nuovo Cimento 49, 183 (1967); and S. Buniatov, E. Zavattini, W. Deinet, H. Muller, D. Schmitt, and H. Staudenmaier, "CERN-Karlsruhe Experiment on Neutral Resonances", submitted to the International Conference on High-Energy Physics, Heidelberg, 20-27 September, 1967.

2. Feldman et al. [M. Feldman, W. Frati, J. Halpern, A. Kanofsky, M. Nussbaum, S. Richert, P. Yamin, A. Choudry, S. Devons, and J. Grunhaus, Phys. Rev. Letters 14, 869 (1965)] reported evidence for such a resonance, called S^0. However, the recent experiment by A. Buhler-Broglin et al. (Ref. 1) is very similar in technique, and they find no evidence for such an effect.

3. The explicit function plotted is $p^2\psi^2$ (p), where ψ(p) is the Fourier transform of the deuteron wave function given by M. Moravcsik, Nucl. Phys. 7, 113 (1958). The selection of our cutoff at 300 MeV/c, as compared to a slightly better choice of 200 MeV/c, introduces at the most 8% nonimpulse events.

4. The quantity "p_{lab}" (π^+) represents an "equivalent" laboratory momentum corresponding to a π^+n collision with the neutron at rest. Events with "p_{lab}" (π^+) less than 1.3 GeV/c were rejected, since a study of t-channel $\pi\pi$ scattering is clearly inappropriate in this region.

5. We have used the latest value from Rosenfeld et al. for $\omega^0 \to \pi^0\gamma$ compared with $\pi^+\pi^-\pi^0$, 10.8 ± 0.9%. (A. H. Rosenfeld, N. Barash-Schmidt, A. Barbaro-Galtieri, W. J. Podolsky, L. R. Price, M. Roos, P. Soding, W. J. Willis, and C. G. Wohl, Lawrence Radiation Laboratory Report UCRL-8030, Sept. 1967).

6. Fits to resonance production plus $3\pi^0$ phase space were attempted, and the results were generally unsatisfactory. However, it was apparent that the amounts of η^0 and ω^0 resulting from these fits would be similar to those from the $2\pi^0$ phase-space fits. Consequently, the amount of η^0 and ω^0 in the neutrals spectrum is derived solely from the four-prong events and a knowledge of the neutral-to-charged branching ratios for these particles.

7. Loyal Durand III and Yam Tsi Chiu, Phys. Rev. Letters 14, 329 (1965).

8. L. D. Jacobs, Ph.D. Thesis, Lawrence Radiation Laboratory Report UCRL-16877, Aug. 1966.

9. The curves of Figs. 2(b) and 3, representing data predominantly at 2.7 GeV/c from E. Malamud and P. E. Schlein, Phys. Rev. Letters 19, 1056 (1967), have been modified in magnitude by a factor $(2.7/p_{lab})^2$,

based on a recent analysis of the 2π energy dependence by the same authors (P. E. Schlein, private communication).

10. This is based on a simple linear extrapolation of the results of Chiu et al. for $2\pi^0$ and $3\pi^0$ cross sections at lower momenta. [C. B. Chiu, R. D. Eandi, A. C. Helmholz, R. W. Kenney, B. J. Moyer, J. A. Poirier, W. B. Richards, R. J. Cence, V. Z. Peterson, N. K. Sehgal, and V. J. Stenger, Phys. Rev. 156, 1415 (1967)].

11. An integration of the data of Fig. 5 of Corbett et al. (Ref. 1) gives a total $\pi^0\pi^0 n$ cross section of 501 μb. Similarly, Fig. 1 (f) of A. Carroll et al., Phys. Rev. Letters 16, 288 (1966), yields an integrated cross section for $N^{*0}n$ of 195 μb, which is consistent with an earlier result of 170 ± 40 μb from Corbett et al., Nuovo Cimento 39, 979 (1965). Based on the former results, this gives an $N^{*0}n$-to-$\pi^0\pi^0 n$ ratio of 40%. Furthermore, by comparison of Figs. 7 and 8 in Ref. 1 (where we assume that a c.m. production cosine of the $\pi^0\pi^0$ system greater than 0.8 has been selected), we conclude that the 40% figure is also valid for the peripheral sample (cosine > 0.8).

12. That fraction of the $3\pi^0$ spectrum due to $\eta^0 \rightarrow 3\pi^0$ has been removed in the $3\pi^0$ phase-space subtraction. A branching fraction of $\eta \rightarrow 3\pi^0/\eta \rightarrow$ all neutrals = 0.28 has been used for these purposes (see Ref. 5).

13. A comparison of the $\pi^0\pi^0 n$ cross section of Corbett et al.[1] of 501 μb at ~2.0 GeV/c with the data of Chiu et al.[10] at 1.44 GeV/c shows that the cross section falls by almost a factor of three over this range. It may not be fortuitous that this factor coincides with the discrepancy between our data and those of Corbett et al.

14. We note that, in addition to the overall energy-dependent renormalization discussed in Ref. 7, an energy-dependent shape factor for beam energies

other than those analyzed in Ref. 9 must be considered. This results from the variation of the Chew-Low boundary and is particularly sensitive in the low-momentum-transfer, high-mass region. A calculation of this effect, based on the t dependence given in Ref. 9, shows that the curve in Fig. 3 should actually fall rapidly to zero above ~850 MeV in comparison with our data (or that of Corbett et al.) This effect becomes negligibly small below ~800 MeV.

15. J. Gezelter, S. Lichtman, F. J. Loeffler, R. J. Miller, and R. B. Willmann, "A Search for the ϵ^0 Meson" (preprint from Purdue University, Lafayette, Indiana); submitted to Nuovo Cimento, July 1967.

16. G. Benson, University of Michigan Technical Report COO-1112-4 (1966).

FIGURE LEGENDS

Fig. 1. (a) Laboratory-system momentum distribution of slower (spectator) proton for 8386 examples of $\pi^+ d \to pp$ + neutrals at 1.1 to 2.3 GeV/c. The curve represents the Fourier transform of the deuteron wave function, approximately normalized to the region 100 to 200 MeV/c.

(b) Effective-mass distribution of the proton (nonspectator) + neutrals system for events shown in (a). For the final analysis, we select a sample with p (spectator) $\leq$ 300 MeV/c and 1.3 $\leq$ "p_{lab}" (π^+) $\leq$ 2.3 GeV/c (4956 events).

Fig. 2. Mass-squared distribution of the neutrals system for (a) $|t$ (0.53 GeV^2)$| \leq 0.20$ (GeV/c)^2 and (b) ≤ 0.08 (GeV/c)^2. The shaded events are a subtraction for $\omega^0 \to \pi^0\gamma$. The solid curve is the best fit to η^0, ϖ^0, and $2\pi^0$ phase space; the dotted curve is $3\pi^0$ phase space, approximately normalized to $M^2 > 0.8$ (GeV)^2. The dashed curve represents the prediction by Malamud and Schlein (Ref. 9). Further requirements on the samples

are p (spectator) $\leq$ 300 MeV/c and 1.3 $\leq$ "p_{lab}" (π^+) $\leq$ 2.3 GeV/c. The plots contain 1947 and 623 events respectively.

Fig. 3. (solid histogram) Neutrals mass spectrum with $\cos_{c.m.}$ (neutrals) $\geq$0.8 for 648 events with 1.8 $\leq$ "p_{lab}" (π^+) $\leq$ 2.3 GeV/c after η^0 and ω^0 subtraction; (solid points) $2\pi^0$ mass spectrum, after subtraction of $3\pi^0$ and N^* background from the solid histogram (232 events); (open points) data from Corbett et al. (Ref. 1), with selection similar to solid points, including an increase of absolute normalization by a factor of 2.96. The solid points are to be interpreted as an indirect measurement of the $2\pi^0$ spectrum from this experiment. Due to the approximations involved in the $3\pi^0$, N^* subtraction, the solid points have a 15% systematic error in addition to the indicated statistical errors. The curve represents the prediction by Malamud and Schlein (Ref. 9).

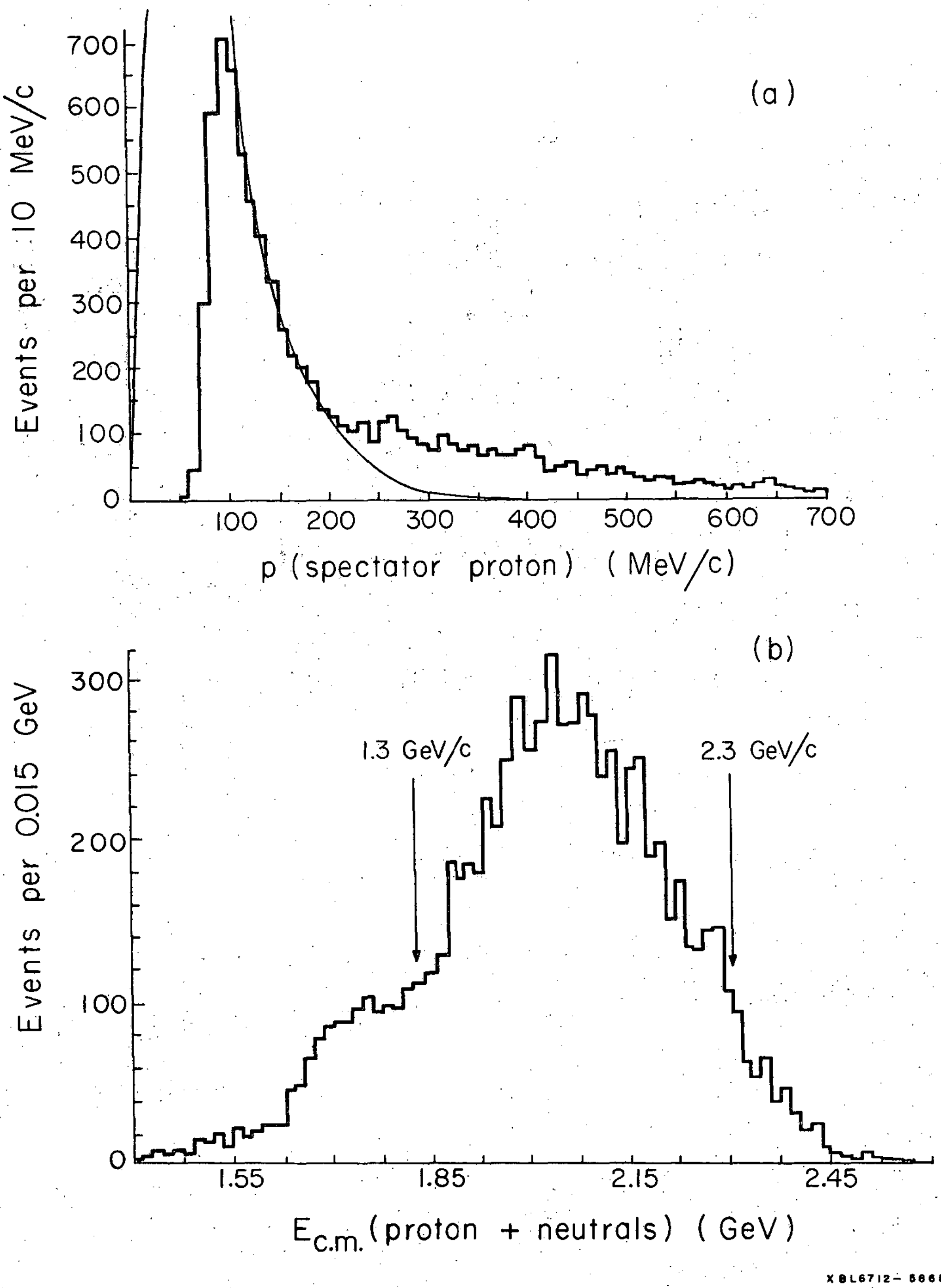
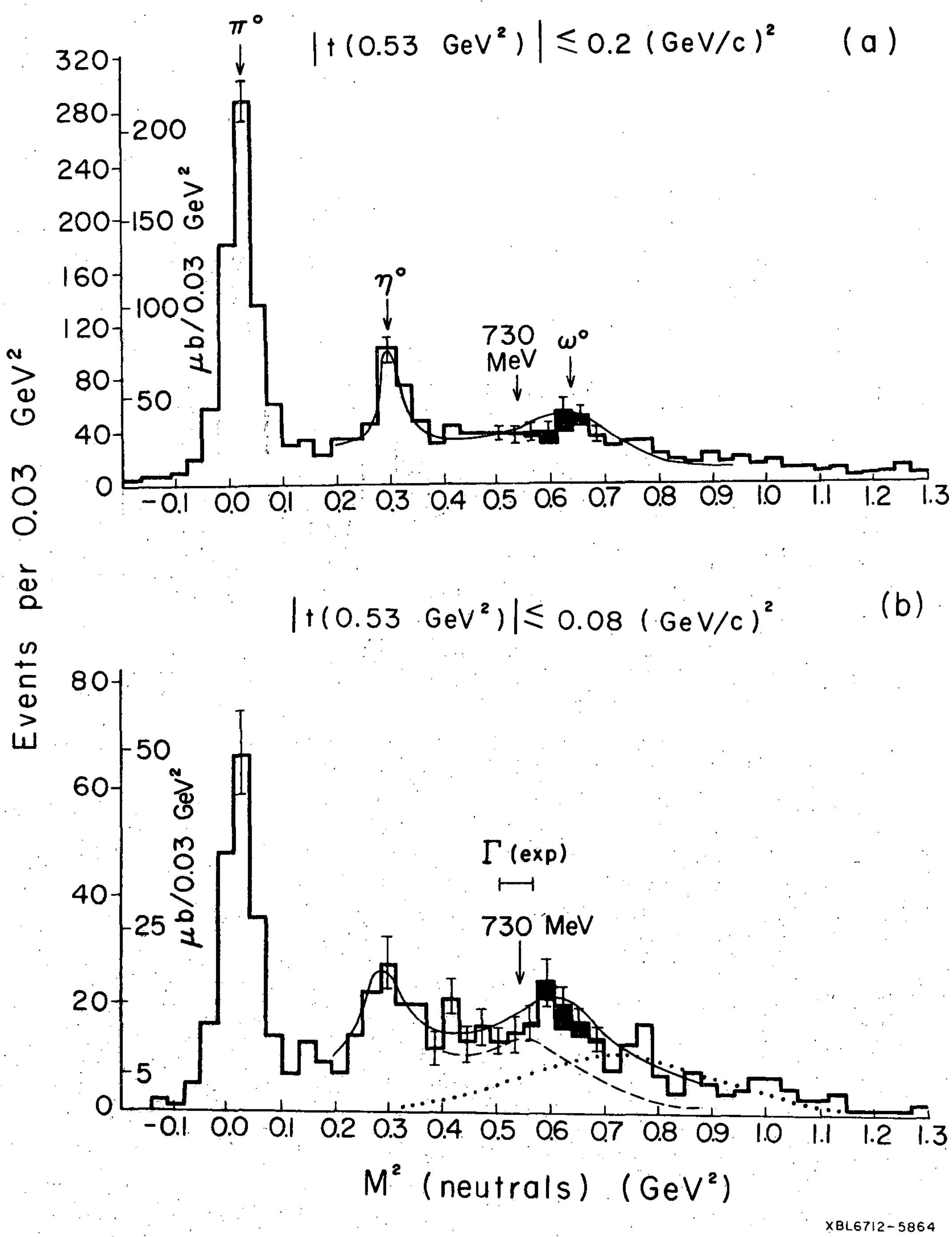

(a)
Events per 10 MeV/c
700
600
500
400
300
200
100
0
100
200
300
400
500
600
700
p (spectator proton) (MeV/c)
(b)
Events per 0.015 GeV
300
200
100
0
1.3 GeV/c
2.3 GeV/c
1.55
1.85
2.15
2.45
E c.m. (proton + neutrals) (GeV)
XBL6712-5666

Fig. 1



π°
|t(0.53 GeV²)| ≤ 0.2 (GeV/c)²
(a)
η°
730 MeV
ω°
Events per 0.03 GeV²
μb/0.03 GeV²
|t(0.53 GeV²)| ≤ 0.08 (GeV/c)²
(b)
Γ (exp)
730 MeV
M² (neutrals) (GeV²)
XBL6712-5864

Fig. 2

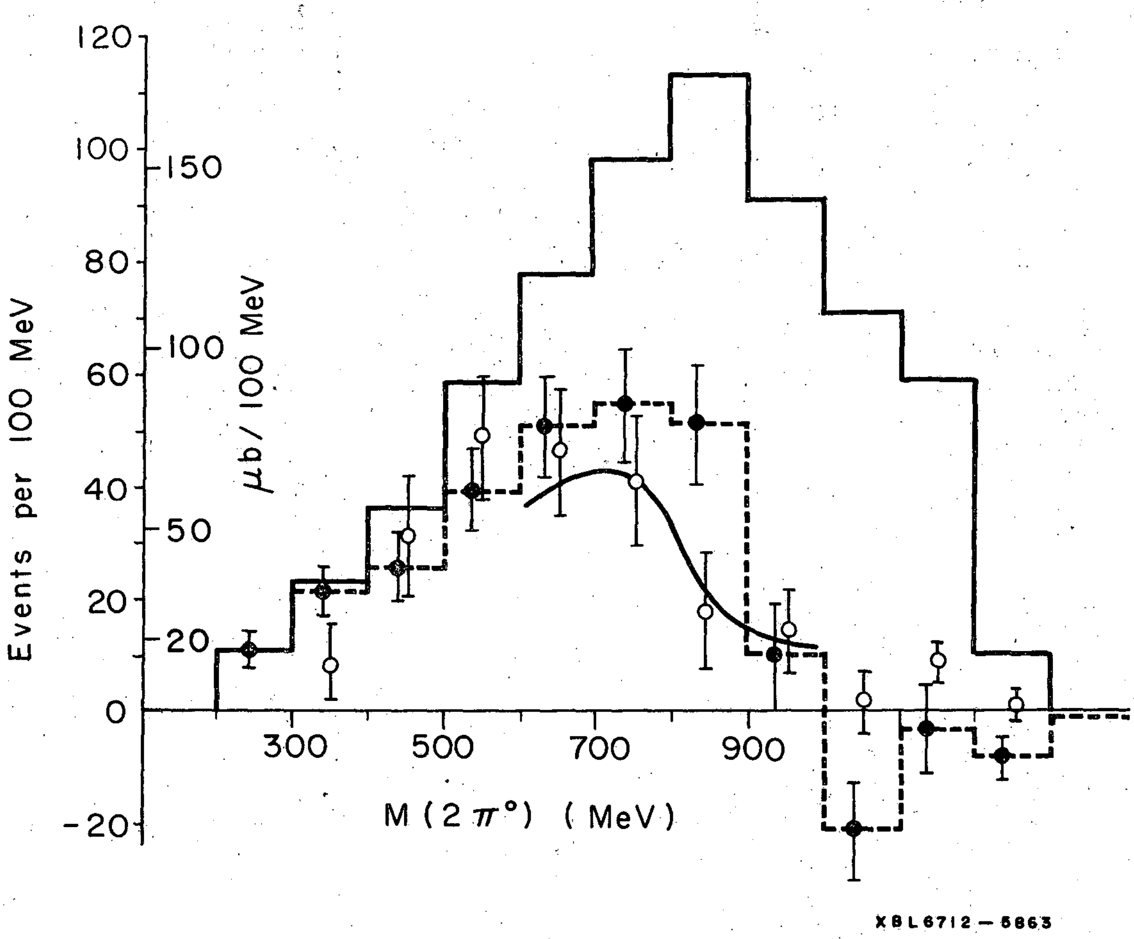

120
100
80
60
40
20
0
-20
150
100
50
20
Events per 100 MeV
μb/ 100 MeV
300
500
700
900
M (2 π°) (MeV)
XBL6712-5863

Fig. 3