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# OBSERVATION OF THE B MESON IN $K^-p$ INTERACTIONS AT 4.2 GeV/c

Amsterdam-CERN-Nijmegen-Oxford Collaboration

S.M. FLATTE(*), J.B. GAY(**), R.J. HEMINGWAY, S.O. HOLMGREN, M.J. LOSTY.
CERN, European Organisation for Nuclear Research, Geneva, Switzerland.

R. BLOKZIJL, J.C. KLUYVER, G.G.G. MASSARO
Zeeman-Laboratorium, Universiteit van Amsterdam, Amsterdam, The Netherlands(***).

W.J. METZGER, J.J.M. TIMMERMANS, R.T. VAN DE WALLE.
Fysisch Laboratorium, Universiteit van Nijmegen, Nijmegen, The Netherlands(***).

P.R. LAMB, P. GROSSMANN
Nuclear Physics Laboratory, Oxford University, Oxford, England.

ABSTRACT

A $\pi\omega$ enhancement at 1245 MeV is observed in the reaction $K^-p \rightarrow \Sigma^+\pi^-\omega$. Its properties agree with those of a B meson produced by natural-parity exchange thus establishing a coupling of the B to a $\bar{K}K^*$ system.

(*) John Simon Guggenheim Memorial Foundation Fellow on leave from the University of California, Santa Cruz, California.

(**) Now at Ecole Polytechnique Fédérale, Lausanne

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The low-lying meson multiplets are particularly important in establishing the quantitative characteristics of hadron spectroscopy. Among these multiplets the $1^+$ systems have received a great deal of study, yet the only well-established resonance in the $1^+$ family continues to be the B meson. The B has been observed as a produced resonance only in the $\pi\omega$ channel; no other decay modes have been established; in fact, the main observations of a clean B signal, in $\pi^{\pm}p$ interactions [1-3], are consistent with an $\omega$ exchange, so that the production input and output channels are both $\pi\omega$ systems [4]. On the other hand, other couplings are expected: for example SU(3) predicts that the coupling constants for $B \rightarrow \bar{K}K^*(890)$ and $B \rightarrow \pi\omega$ are in the ratio of 3:2. However the threshold of the $KK^*(890)$ system is ~ 1380 MeV, well above the mass of the B.

In this paper we report an observation of a $\pi\omega$ enhancement at 1245 ± 11 MeV in the reaction $K^-p \rightarrow \Sigma^+\pi^-\omega$ at 4.2 GeV/c. The properties of the enhancement (mass, width, branching ratios, spin-parity, helicity decay amplitudes, t'-slope and density matrix) agree with those of a B meson produced by $K^*$ exchange, thus establishing a coupling of the B to $\bar{K}K^*$, where the $K^*$ has natural parity.

The data come from an exposure of the CERN 2m Hydrogen Bubble Chamber and correspond to a sensitivity of 97 events/μb. We have 13 699 weighted events (corresponding to 9052 events) of the reaction:

$$K^-p \rightarrow \Sigma^+\pi^-\pi^+\pi^-\pi^o \qquad (1)$$

with a selection $t' < 1\ \mathrm{GeV}^2$, where $t' = t_{min} - t$, and t is the 4-momentum transferred from proton to $\Sigma^+$. Details of the treatment of ambiguities with other reactions are not crucial to the properties of our final event sample because we will be concerned only with events of the subreaction

$$K^-p \rightarrow \Sigma^+\pi^-\omega \qquad (2)$$

containing the narrow $\omega$ meson. We have chosen all events of reaction (1) whose fit has a confidence level of greater than 0.5%, and which do not have a sucessful 4-constraint fit. There is a remaining ambiguity (in less than 5% of our events) between various $\Sigma^+$ decay hypotheses (low vs high momentum, and $n\pi^+$ vs $p\pi^0$ decay) which has been resolved in favour of the highest confidence level fit.

Event weights have been used to account for $\Sigma^+$ tracks lost due to short length or small angle decay. $\Sigma^+$ with projected length less than 5 mm or projected decay angle less than 60 mr have been eliminated to avoid any uncertainty in this loss. Since the t' cut has restricted our sample to relatively low momentum $\Sigma^+$, the scanning efficiency for the events remaining in our sample is very good (98 ± 2%), and the calculation of the weight to correct for the lost decays is straightforward ($\bar{w} \simeq 1.5$).

Fig. 1 shows the $\pi^+\pi^-\pi^0$ mass distribution for events of reaction (1). A clear $\omega$ signal over a non-negligible (~ 20%) background is seen. Defining $\pi^+\pi^-\pi^0$ combinations in the indicated central band as $\omega$'s, we show the $\Sigma^+\pi^-\omega$ Dalitz plot in fig. 2 (in the case of double $\omega$'s we choose the $3\pi$ mass closest to 783.4 MeV). The prominent features are the $\Lambda(1405)$ and $\Lambda(1520)$ in the $\Sigma^+\pi^-$ system, and a broad band centered at a $\pi^-\omega$ mass of about 1.23 GeV. From inspection of the Dalitz plot this band, which contains over 1000 events, is not a reflection of some $Y^*$ system. The band shows clearly as an enhancement in the $\pi^-\omega$ mass-squared projection of the Dalitz plot. The remainder of this paper is devoted to the determination of the properties of this enhancement.

In order to purify our sample we have subtracted background under the $\omega$ and eliminated the prominent $Y^*$'s. The $\omega$ background subtraction was accomplished by using events in the control bands (see fig. 1) with a wieght of −1/2. We have always used the $3\pi$ combination whose mass is closest to the $\omega$ mass (see shaded area of fig. 3(a)). The resulting $\pi\,\omega$ mass distribution (fig. 3(b)) shows the enhancement even more clearly. The $Y^*$'s are still present (fig. 3(c)). We eliminate the $Y^*$'s by requiring $\cos\theta < 0.3$, where $\theta$ is the angle between the $\pi^-$ in the $\pi^-\omega$ rest frame and the $\Sigma^+$ in the overall center of mass(*). We have compensated for the selection by doubling the weight of events with $\cos\theta < -0.3$. This "repopulation" technique allows us to calculate symmetrized moments of

(*) All angles and moments used in our analysis are consistent with the notation of ref. [1].

the decay of the $\pi\omega$ system (see ref. [1] for details), and is valid under the condition that there are no significant interferences between $\pi\omega$ systems of opposite parity (this has been checked in the region $|\cos\theta| < 0.3$). Fig. 3(a) shows the $3\pi$ mass distributions for $t' < 1$ GeV$^2$ and $Y^*$ removed by the above technique (open circles). The mass, width, spin-parity behaviour, and density matrix of our $\pi\omega$ enhancement will now be determined from our purified sample.

Mass and width: The $\pi^-\omega$ mass distribution for our purified sample is shown in fig. 3(d). A fit to an s-wave Breit-Wigner plus a quadratic background (all multiplied by phase space) yields a mass of 1245 ± 11 MeV and a width of 182 ± 45 MeV. The best fit (fig. 3(d)), yielded 890 ± 150 events in the enhancement, which, when corrected for $\omega$ tails and neutral decays, corresponds to a cross section of 14 ± 2 μb. Although a peripherally produced $\Sigma^+\pi^-\omega$ final state might produce a low-mass peaking due to the $t_{min}$ effect, Monte Carlo studies have shown that this peaking could not explain the narrowness of the enhancement. The mass and width we have obtained are consistent with those of the B meson [5] . In our further investigation we shall assume we are dealing with the B meson, and we shall show that our observations are consistent with that assumption.

t'-slope: Following the above procedure for four t' bins, we found the amount of B production as a function of t' (assuming M = 1245 MeV and $\Gamma$ = 182 MeV) and determined an exponential slope parameter of 4.0 ± 0.8 GeV$^{-2}$, to be compared with 5.5 ± 1.8 GeV$^{-2}$ for $\pi^+ p \rightarrow pB^+$ at 7.1 GeV/c [1].

Spin-parity behaviour: Table I gives the important symmetrized moments for our sample in the B region (other moments are consistent with zero). Also shown are the same moments from a sample of B events produced in $\pi^+p$ interactions at 7.1 GeV/c [1], normalized to the same number of events. The $\pi^+p$ results were shown by Chung et al. to be consistent with the B having spin-parity $1^+$ and being produced by natural-parity exchange. In addition Chung et al. showed that these moments were not compatible with other possible spin-parity assignments (such as $0^-$, $1^-$, $2^+$ or $2^-$).

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The compatibility of the moments between the two experiments is a remarkable confirmation that we are looking at the B. In addition we have made a fit to these moments with a pure $1^+$ amplitude to determine the helicity decay amplitudes and density matrix for the B region. The fit utilized the full error matrix for the 14 moments, and had a confidence level of 60%. Table I shows the results, again compared to the values obtained by Chung et al. The helicity decay amplitude $|F_o|^2$ is a property of the resonance only(*), and must be the same in all samples of the B (except for background effects), but the density matrix depends on the production mechanism, and the fact that the three density matrix elements are compatible between the two experiments, added to the similarity of t' slopes, indicates that natural-parity exchange of the same type dominates both [1].

Branching ratios: The final state $\Sigma^+\pi^-K^+K^-$ was investigated for possible evidence of other decay modes for the enhancement. No enhancement was seen, at a level of 5% for $B \rightarrow \phi\pi$ and $K\bar{K}\pi$ decays. Previous results on the B also saw no evidence for these modes [5].

Other production mechanisms: The reaction

$$K^-p \rightarrow \Sigma^+(1385)\pi^-\omega \qquad (3)$$

was also investigated for possible B production. Selection of the sample was similar to that of reaction (1).

Fig. 4(a) shows the $\pi^-\omega$ mass distribution recoiling off the $\Sigma^+(1385)$. No enhancement is seen. An upper limit of 2 μb for the cross section of $\Sigma^+(1385)B^-$ production may be compared to 14 ± 2 μb observed for $\Sigma^+B^-$. This ratio explains why the B has not been seen in $K^-p$ interactions before; almost all searches have been in reaction (3), very few previous experiments have even scanned for reaction (1).

We have also investigated reaction (2) for backward $B^-$ production. None was seen, with an upper limit of 2 μb.

(*) Our $F_o$ value of 0.5 corresponds to a D/S ratio of 0.1.

Conclusions: We have observed a clear $\pi\omega$ enhancement of over 1000 events in the reaction $K^- p \to \Sigma^+ \pi^- \omega$ at small t'. The mass, width, spin-parity, helicity decay amplitude and branching ratios of the enhancement are consistent with it being the B meson. The t'-slope and density matrix of the B strongly favors the production mechanism being t-channel, natural-parity exchange, suggesting $K^*$ exchange. The cross section is estimated to be 14 ± 2 μb. Our observation establishes a coupling of the B to a $\bar{K}K^*$ system where the $K^*$ has natural parity.

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$K^{-}n$, W. Hoogland et al., Phys. Letters 33B (1970) 631 and
R. Berg et al., Nucl. Phys. B39 (1972) 509.

[5] Particle Data Group, Rev. Mod. Physics 48 (1976) S1.

TABLE I

SPIN-PARITY BEHAVIOUR OF THE B

For $t' < 1$ GeV$^2$ and $1.08 < M(\pi\omega) < 1.38$ GeV, we have determined the moments of the $\pi\omega$ system decay. The events have not been weighted for $\Sigma$ decay. Our results are compared with a similar B sample observed in $\pi^+p$ interactions, which we have normalized to our total number of events [1]. The values of $|F_o|^2$, $\rho_{11}$, $\rho_{1-1}$, and Re $\rho_{10}$ were determined in our case assuming a pure $1^+$ state, and in the $\pi^+p$ case allowing for $1^-$ and $0^-$ background.

| Quantity | $K^-p \rightarrow \Sigma^+B^-$ | $\pi^+p \rightarrow pB^+$ |
|---|---|---|
| $\|F_o\|^2$ | 0.25 ± 0.05 | 0.16 ± 0.03 |
| $\rho_{11}$ | 0.17 ± 0.03 | 0.23 ± 0.02 |
| $\rho_{1-1}$ | -0.07 ± 0.04 | -0.13 ± 0.03 |
| Re $\rho_{10}$ | 0.12 ± 0.03 | 0.09 ± 0.02 |
| H(0000) | 703 ± 40 | 703 ± 24 |
| H(0020) | -23 ± 17 | -17 ± 12 |
| H(0021) | 3 ± 14 | 2 ± 8 |
| H(0022) | 2 ± 13 | -7 ± 7 |
| 5H(2000) | -171 ± 89 | -283 ± 52 |
| 5H(2020) | 108 ± 39 | 69 ± 27 |
| 5H(2021) | 103 ± 31 | 48 ± 17 |
| 5H(2022) | 26 ± 26 | 30 ± 14 |
| 5H(2120) | 58 ± 33 | 25 ± 16 |
| 5H(2121) | 42 ± 20 | 35 ± 12 |
| 5H(2122) | 26 ± 18 | 22 ± 11 |
| 5H(2220) | 164 ± 29 | 79 ± 16 |
| 5H(2221) | 46 ± 20 | 32 ± 12 |
| 5H(2222) | 16 ± 21 | 65 ± 14 |

FIGURE CAPTIONS

Fig. 1 $\pi^+\pi^-\pi^o$ mass distribution from $K^-p \rightarrow \Sigma^+\pi^-\pi^+\pi^-\pi^o$, $t' < 1$ GeV$^2$, two combinations per event. The shaded histogram results from selecting the $\pi^+\pi^-\pi^o$ combination closest to the $\omega$ mass. The bands indicating the $\omega$ region and two control regions are used to define $\omega$ events, and to subtract background in subsequent analysis.

Fig. 2 Dalitz plot of $\Sigma^+\pi^-\omega$ final state. A selection of $t' < 1$ GeV$^2$ has been made. The prominent features are $\Lambda(1405)$ and $\Lambda(1520)$ in the $\Sigma^+\pi^-$ system, and B production in the $\pi\omega$ system.

Fig. 3 Mass distributions for the $\Sigma^+\pi^-\omega$ final state with events weighted for $\Sigma$ losses; $t' < 1$ GeV$^2$:

a) $\pi^+\pi^-\pi^o$ distribution in the $\omega$ region. Eliminating $Y^*$'s by a repopulation technique (see text) yields the open circles.

b) $\pi\omega$ mass distribution with background subtracted under the $\omega$.

c) $\Sigma^+\pi^-$ mass distribution with $\omega$ background subtraction.

d) $\pi\omega$ mass distribution with $\omega$ background subtraction and $Y^*$'s eliminated. The curve is a Breit-Wigner plus polynomial background fit (see text).

Fig. 4 $\pi^-\omega$ mass distribution for the final state $\Sigma^+(1385)\pi^-\omega$ with $t' < 1$ GeV$^2$, no $\omega$ background subtraction. No B is seen.

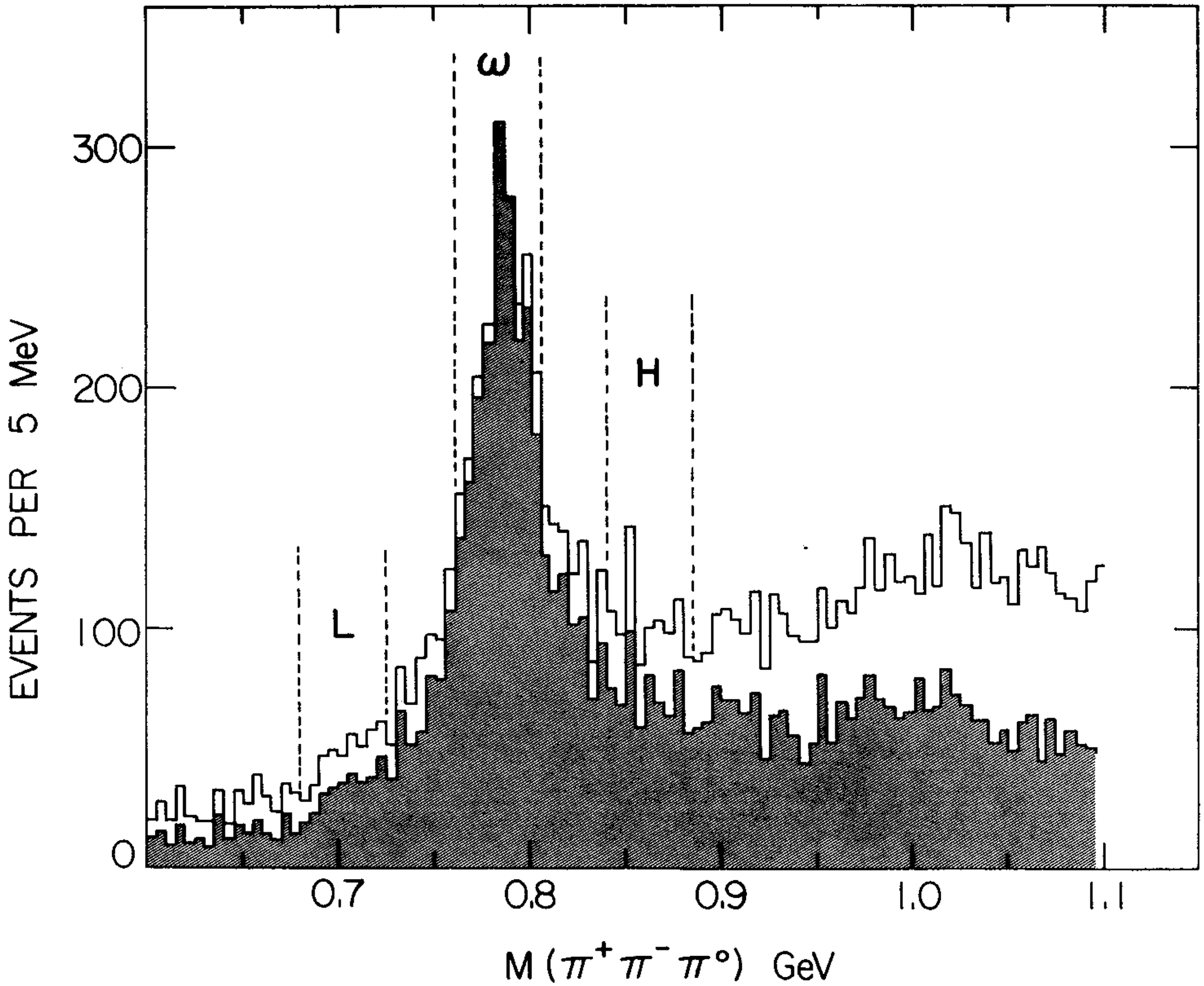


Fig. 1

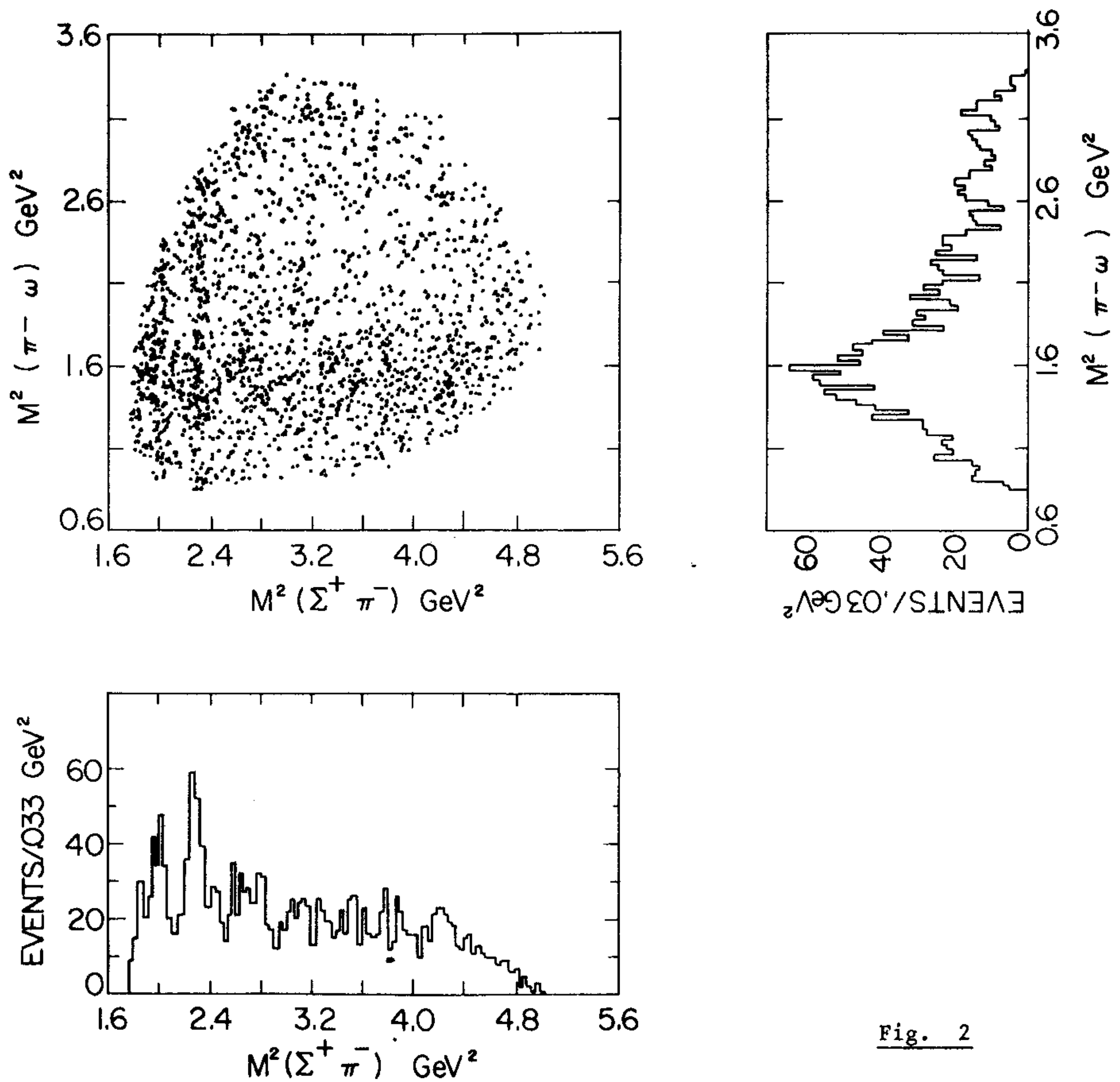
3.6
2.6
1.6
0.6
M² (π⁻ ω) GeV²
1.6
2.4
3.2
4.0
4.8
5.6
M²(Σ⁺ π⁻) GeV²
EVENTS/.03 GeV²
0
20
40
60
EVENTS/.033 GeV²

Fig. 2

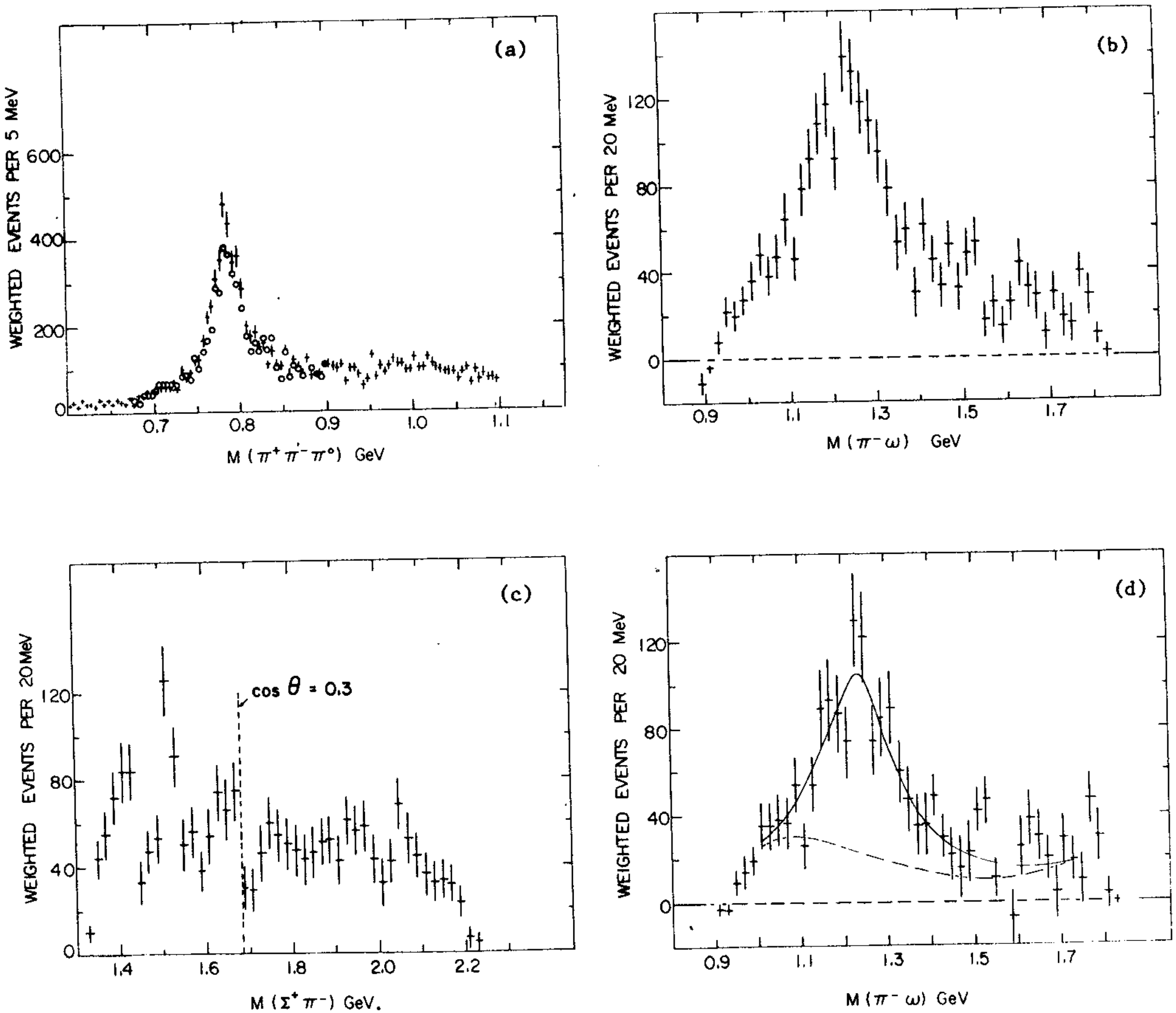
(a)
WEIGHTED EVENTS PER 5 MeV
600
400
200
0
0.7
0.8
0.9
1.0
1.1
M ($\pi^+\pi^-\pi^0$) GeV
(b)
WEIGHTED EVENTS PER 20 MeV
120
80
40
0
0.9
1.1
1.3
1.5
1.7
M ($\pi^-\omega$) GeV
(c)
WEIGHTED EVENTS PER 20 MeV
120
80
40
0
cos $\theta$ = 0.3
1.4
1.6
1.8
2.0
2.2
M ($\Sigma^+\pi^-$) GeV.
(d)
WEIGHTED EVENTS PER 20 MeV
120
80
40
0
0.9
1.1
1.3
1.5
1.7
M ($\pi^-\omega$) GeV

Fig. 3

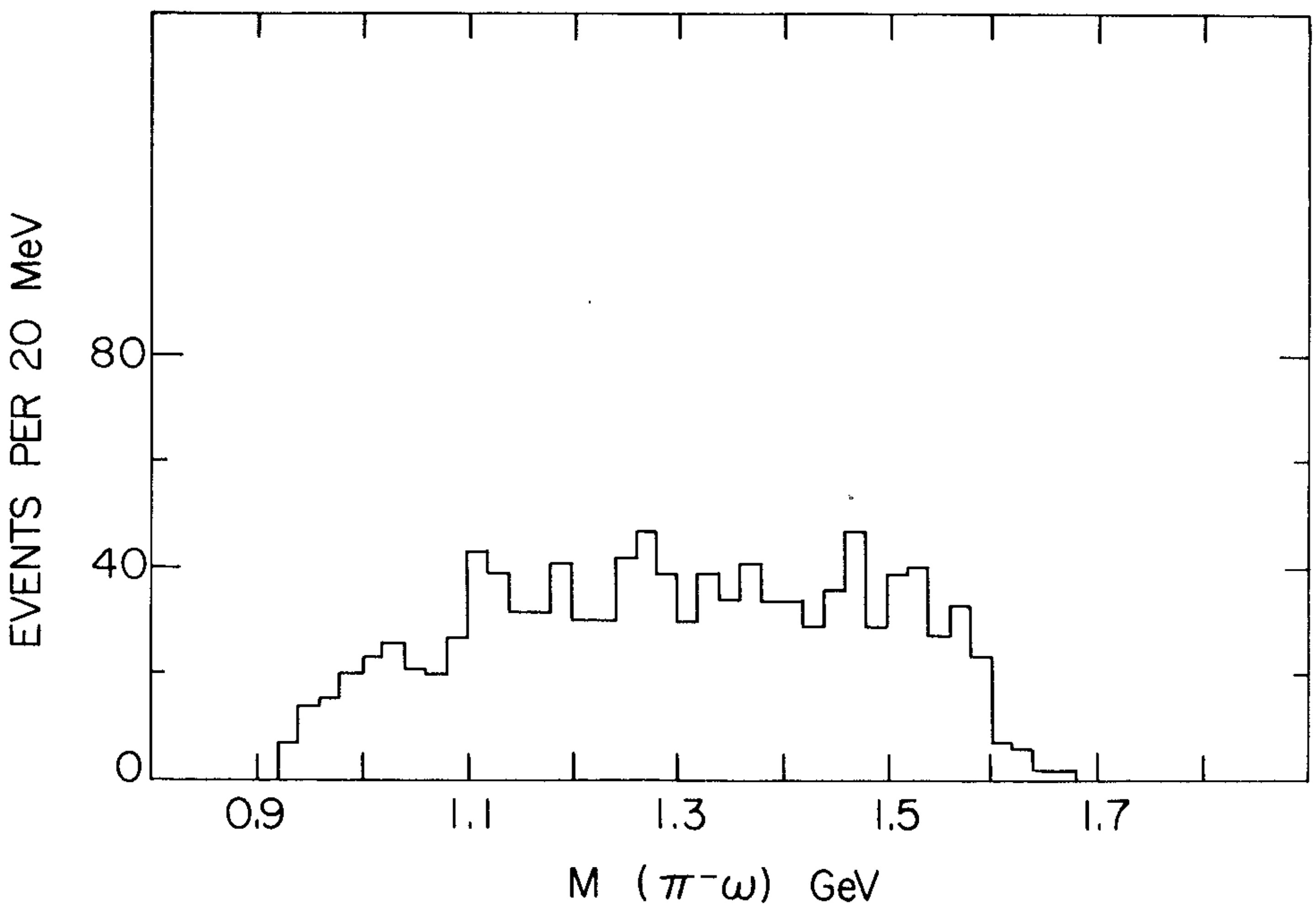


Fig. 4

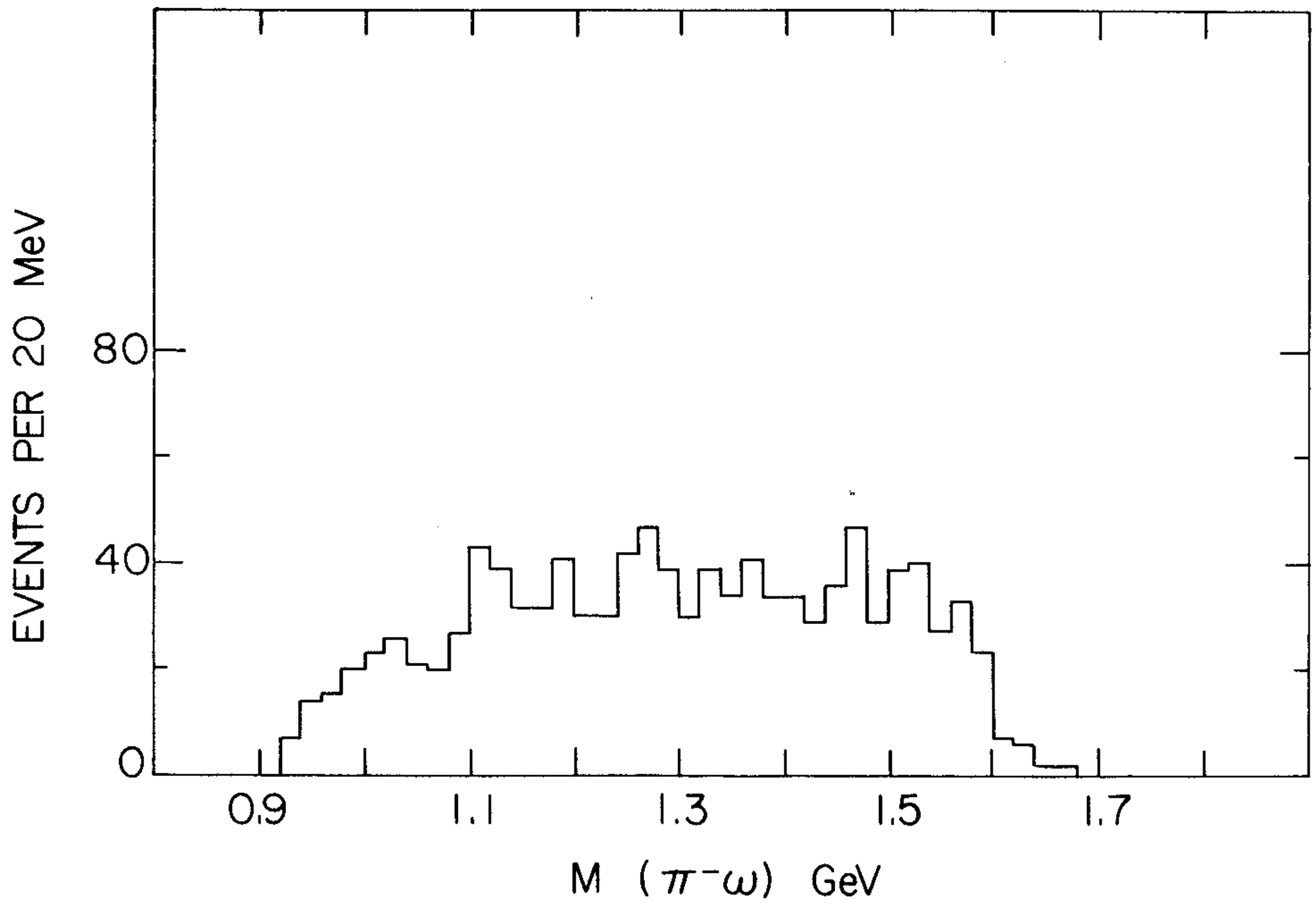


Fig. 4