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REVIEW OF SPIN-PARITY ANALYSES OF $\pi\omega$ AND $K\omega$ SYSTEMS*

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The purpose of this talk is to give a review of the progress in spin-parity (J^P) analyses on the $\pi\omega$ system.(1) In addition, first attempts at a similar analyses on the $K\omega$ system near the threshold are presented and its production and decay properties compared with those of the $\pi\omega$ system.

There are five new works on the $\pi\omega$ J^P analysis, one(2) a re-analysis of the work presented at the NAL Conference and the other four,(3-6) submitted to this conference, representing new endeavors on this subject. All these works find that the most likely J^P for the B is 1^+. In particular, Chung, et al.,(3) Chaloupka,(4) and Morrison, et al.,(6) have independently performed mass-independent partial-wave analyses in which the possibility of interference among different J^P states is explicitly taken into account. They find that the B region is dominated by a 1^+ wave, produced mainly by natural-parity exchange. The same conclusion is also reached by Karshon, et al.,(5) who have performed a more conventional background-subtracted moment analysis.

One may ask the question: Does a $\pi\omega$ system around 1250 MeV harbor just one resonant 1^+ wave? Although a preponderance of evidence coming from πp interactions indicates that the 1^+ wave is the only one with a "bump" structure in this region, one cannot as yet give a definitive answer due mainly to the fact that the partial-wave solutions are not unique if interference effects are allowed in the analysis. Chung, et al.,(3) find that an adequate description of their data can be achieved with the waves 2^-, 1^- and 0^- in and below the B region (N.B. no 1^+ wave in the solution!). There are unpleasant aspects to this solution, such as a large ρ_{22} component for the 2^- state and the possibility of two resonances 2^- and 1^- in the B region. Also the goodness of fit to the data for this solution is not as good as that for the 1^+ solution. However, they feel that the solution cannot be ruled out with mathematical certainty at this time.

There are hints that a 1^- object, so-called $\rho'(1250)$, might exist in the $\pi\omega$ system in the vicinity of the B. Frankiel, et al.,(7) from study of the reaction $\bar{p}p$(at rest) $\rightarrow \pi^+\pi^-\omega$, find that the data require both 1^+ and 1^- objects in the B region. It would be of some interest to see if the situation persists when the assumption of S-wave capture of the $\bar{p}p$ system is relaxed (this is what they assumed in the analysis). On the other hand, Ballam, et al.,(8) observe an enhancement at 1.24 GeV in the reaction $\gamma p \rightarrow p\pi^+\pi^-$ MM at 2.8, 4.7 and 9.3 GeV (see Fig. 1). They argue that the

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most likely decay mode of the object "B" is $\pi^o\omega$ and, in addition, they claim that the production cross-section is nearly constant as a function of the photon energy, suggesting Pomeron exchange. Then the simplest explanation of their data would be the presence of a diffractively produced 1^- object, namely the $\rho'(1250)$. However, one cannot rule out the possibility that the genuine $J^P=1^+$ B-meson is produced diffractively in this reaction, violating the Morrison-Gribov rule. An additional hint for the $\rho'(1250)$ comes from the e^+e^- experiments. Conversi, et al.,(9) in a paper submitted to this Conference, argue that they see evidence of the $\rho'(1250) \to \pi^o\omega$ in the reaction $e^+e^- \to \pi^+\pi^-\pi^o\pi^o$. The statistics, as is seen in Fig. 2, is too meager to be taken seriously; more data are clearly needed to clear up the situation here.

For completeness, a few relevant details are given from the papers on the B analysis submitted to the Conference. The $\pi\omega$ mass spectra from these papers are shown in Figs. 3a-c, 4a, 5a, and 7a. The mass of the B is typically found to be in the range 1220 to 1240 MeV and the width in the range 130 to 160 MeV. An important parameter from the theoretical point of view is the decay amplitudes of the $J^P=1^+$ B-meson. They can be expressed in terms of either the helicity decay amplitude F_λ (λ is the ω helicity) or the orbital angular momentum for the $\pi\omega$ decay (D and/or S wave for the $J^P=1^+$ object). The measured values of these are given in Table I; it is seen that $|F_o|^2$ is relatively small. However, according to Chung, et al.,(3) $|F_o|^2$ is definitely non-zero. The best evidence comes from a plot of the unnormalized moment which is proportional to $|F_o|^2$ (see Fig. 5c); this plot shows a bump structure in the B region, demonstrating that $|F_o|^2$ cannot be zero. From a partial-wave analysis of the $\pi\omega$ system, they quote $|F_o|^2 = 0.16 \pm 0.04$ for the $J^P=1^+$ B-meson.

Rosner,(10) in discussing the $SU(6)_W$ classification scheme, asserts that the $|F_o|^2$ is the only free parameter describing nearly all decays of the 0^+, 1^+ and 2^+ families. He finds that a satisfactory description of these decays emerges using the value 0.13 for $|F_o|^2$. In addition, there is the work of P. Shen and K. Kang,(11) who did a N/D dynamical calculation of the $\pi\omega$ scattering process. They find a resonant state in the 1^+ wave and predict 0.18 for the ratio $|D/S|$ for this state, which is compatible with the experimental measurements (see Table I).

Turning now to some further details of the J^P analyses, one can see that the $\pi\omega$ region below and in the B is nearly all in the 1^+ state, as seen in Figs. 6 and 7a (the points with error bars). Chung, et al.,(3) quote for the density-matrix elements $\rho_{mm'}$ of the 1^+ state: $\rho_{11} = 0.23 \pm 0.02$, $\rho_{1-1} = -0.13 \pm 0.03$, and $Re\rho_{10} = 0.09 \pm 0.02$, evaluated in the s-channel helicity frame with $t' < 1\ GeV^2$. Note that both ρ_{oo} and $\rho_{11} - {}_{1-1}$ are large and significantly non-zero; this indicates the importance of the natural-parity exchange in the B production. The same conclusion is reached by Chaloupka,(4) as is seen in his plots of $N\rho_{oo}$, $N(\rho_{11}-\rho_{1-1})$ and $N(\rho_{11}+\rho_{1-1})$ for the 1^+ state (Figs. 7b, 7c and 7d). In addition, Karshon, et al.,[5] reach the same conclusion from their analysis of the background-subtracted moments. Finally, it should be pointed out that all the analyses find a sharp forward peak in the $d\sigma/dt'$ distribution for the 1^+ state (see Fig. 8) and that the slope of the t' distribution is roughly $3\sim4$ for $t' < 1$ GeV^2. For comments on the exchange mechanisms relevant for the B production, see the reviews by G. Fox[12] and by G. Kane.[13]

No extensive partial-wave analysis of the $K\omega$ system has yet been performed due mainly to paucity of statistics. First attempts at the $K\omega$ analysis, as submitted to this Conference, have been made by Protopopescu, et al.,[14] at BNL and by the ABBCHLV collaboration.[6] Their analyses of the threshold enhancement (see Figs. 9 and 3d) find that the 1^+ wave is dominant. In addition, Protopopescu, et al., quote $|D/S| = 0.08 \pm 0.08$ and $\rho_{oo}(1^+) = 1.0 \pm 0.1$ for $M(K\omega)$ in the range 1.24 to 1.40 GeV. Thus, it is seen that a predominantly S-wave 1^+ state is produced (presumably) by Pomeron exchange. Further evidence of Pomeron exchange is afforded by the p_{LAB}^{-n} behavior of the $K\omega$ cross-section. As shown in Fig. 10 (provided by Morrison[6]), $n \simeq 0$ for the $K\omega$ threshold region, indicating Pomeron exchange for the $K\omega$ system. In contrast, the $\pi\omega$ threshold region has a markedly different cross-section dependence ($n \simeq 2.3$), indicating importance of exchange other than the Pomeron.

The situation regarding the $\pi\omega$ system may be summarized as follows. The B-meson has $J^P=1^+$ with the $|D/S|$ ratio between 0.2 and 0.3, and the B production from πp interactions is mostly via natural-parity exchange with a sharp forward peak in the t' distribution. The spin-parity for the B is most unlikely to be anything other than 1^+, although it is not impossible to fit the B region with a solution (rather unsatisfactory in some respects) containing little 1^+ wave. The situation regarding the B region from the $\bar{p}p$(at rest), γp and e^+e^- interactions is less satisfactory. Here a real possibility exists for a 1^- object in the B region; however, the evidence is not yet compelling, and a more sophisticated analysis on more abundant statistics (e^+e^- in particular) is sorely needed.

The $K\omega$ threshold region is found to be mainly in the $J^P=1^+$ state. However, unlike that of the $\pi\omega$ system, the $K\omega$ production from K^-p interactions is almost purely via Pomeron exchange. From the generalized Morrison-Gribov rule, then, the $K\omega$ threshold region has its C parity positive, the same as that of the K^- incident particle. Therefore, even if the $K\omega$ threshold enhancement turns out to be dominated by a genuine resonance, it is not likely to belong to the same octet to which the B belongs, for C is negative for the B meson.

So, for the moment, the B "stands" by itself, and there is as yet no clear indication where the strange member or the isoscalar partners of the B are to be found.

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TABLE I

Reference	B Events[a]	$\|F_o\|^2$	$\|D/S\|$[c]
N. Armenise, *et al.*[2] π^-p at 9.1 GeV/c	78	0.27 ± 0.13	-
S. Chung, *et al.*[3] π^+p at 7.1 GeV/c	1092[b]	0.16 ± 0.04	0.21 ± 0.07[d]
V. Chaloupka[4] π^-p at 3.9, 5, and 7.5 GeV/c	1950[b]	0.10 ± 0.06	0.30 ± 0.10[d]
U. Karshon, *et al.*[5] π^+p at 5 GeV/c	584	0.08 ± 0.08	0.35 ± 0.25[d]

(a) Estimated B events in the interval $1.1 < M(\pi\omega) < 1.4$ GeV.

(b) These are the 1^+ events obtained from the partial-wave analysis of the $\pi\omega$ system in the B region with $t' < 1$ GeV^2 (0.6) for Chung (Chaloupka).

(c) $D = \sqrt{\frac{2}{3}}\,(-F_o+F_1)$, $S = \sqrt{\frac{1}{3}}\,(F_o+2F_1)$.

(d) These analyses find F_o and F_1 relatively real and $F_oF_1 > 0$.

FIGURE CAPTIONS

1. $M(\pi^+\pi^-MM)$ from the reaction $\gamma p \to p\pi^+\pi^-$ + neutrals at $E_\gamma = 2.8$, 4.7 and 9.3 GeV (Ref. 8). The shaded histograms result from a selection which tends to favor the $\pi^o\omega$ decay mode of the "B" over others.
2. Cross-section vs. center-of-mass energy for the reaction $e^+e^- \to \pi^+\pi^-\pi^c\pi^o$ (Ref. 9).

3(a-c) $M(\pi^+\omega)$ from the reaction $\pi^+p \to \pi^+\omega p$ at 4, 5, 8, and 16 GeV/c.
(d) $M(K^-\omega)$ from the reaction $K^-p \to K^-\omega p$ at 10 and 16 GeV/c (Ref. 6).

4(a) $M(\pi^+\omega)$ from the reaction $\pi^+p \to \pi^+\omega p$ at 5 GeV/c (Ref. 5); the lower histogram results after the elimination of the $\Delta^{++}\omega$ events.
(b) Unnormalized moments proportional to $3|F_o|^2-1$.

5(a) $M(\pi^+\omega)$ from the reaction $\pi^+p \to \pi^+\omega p$ at 7.1 GeV/c with $\Delta^{++}\omega$ events out and $t' < 1$ GeV^2 (Ref. 3); the events from the ω control region have been included with appropriate negative weights to "eliminate" the non-ω background events.
(b)[c] Unnormalized moments proportional to $|F_1|^2$ [$|F_o|^2$].
(d)[e] Unnormalized moments which should be zero if the $\pi\omega$ system is in the 1^+ [2^-] state.

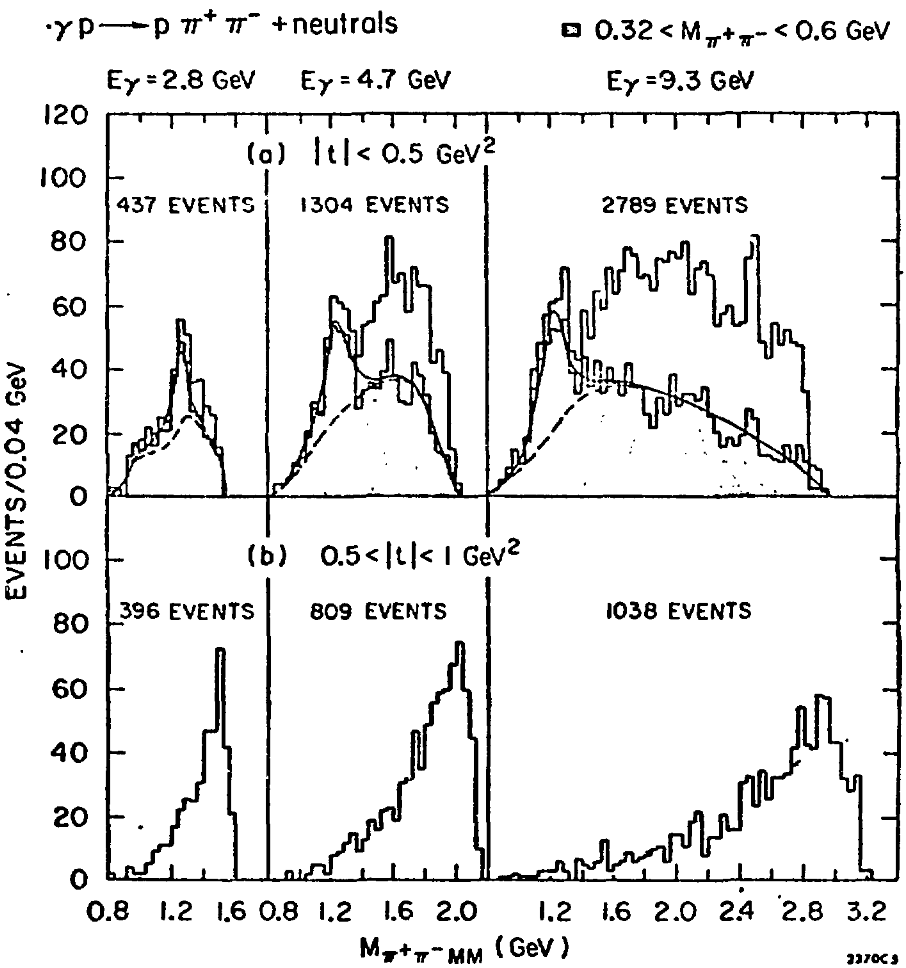
6. Fitted numbers of events in states of $J^P=1^+$, 0^- and 1^- as a function of $M(\pi^+\omega)$ (Ref. 3).

7(a) $M(\pi^-\omega)$ from the reaction $\pi^-p \to \pi^-\omega p$ at 3.9, 5 and 7.5 GeV/c with $N^*\omega$ events out (Ref. 4); the points with error bars correspond to fitted events with $J^P=1^+$.
(b-d) $N\rho_{oo}$, $N(\rho_{11}-\rho_{1-1})$ and $N(\rho_{11}+\rho_{1-1})$ for the 1^+ wave where N stands for the 1^+ events; $\rho_{mm'}$ are evaluated in the Jackson frame.
(e) $|D/S|$ for the 1^+ wave as a function of $M(\pi^-\omega)$.

8. $d\sigma/dt'$ distribution for the 1^+ wave at 3.9 GeV/c (Ref. 4). Solid bars correspond to fitted events from the partial-wave analysis. The dashed bars correspond to the events found in a mass fit to the B region.

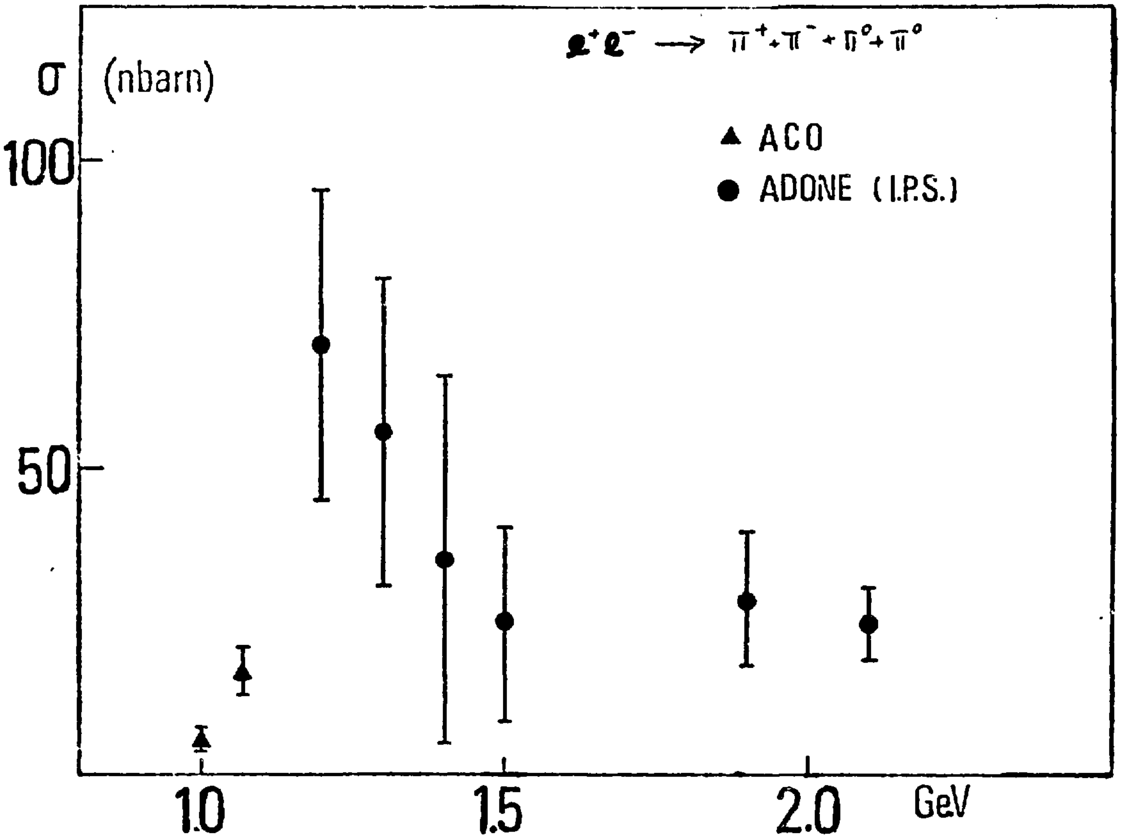
9(a) $M(K^-\omega)$ for the reaction $K^-p \to K^-\omega p$ at 7.3 GeV/c (Ref. 12).
(b) The same spectrum with non-ω background events subtracted out (cf. Fig. 5a).

10. Fit of $\sigma \sim p_{LAB}^{-n}$ to the reactions $\pi^+p \to \pi^+\omega p$ and $K^-p \to K^-\omega p$ (Ref. 6); fitted exponents n vs. $M(\pi^+\omega)$ and $M(K^-\omega)$ are plotted.



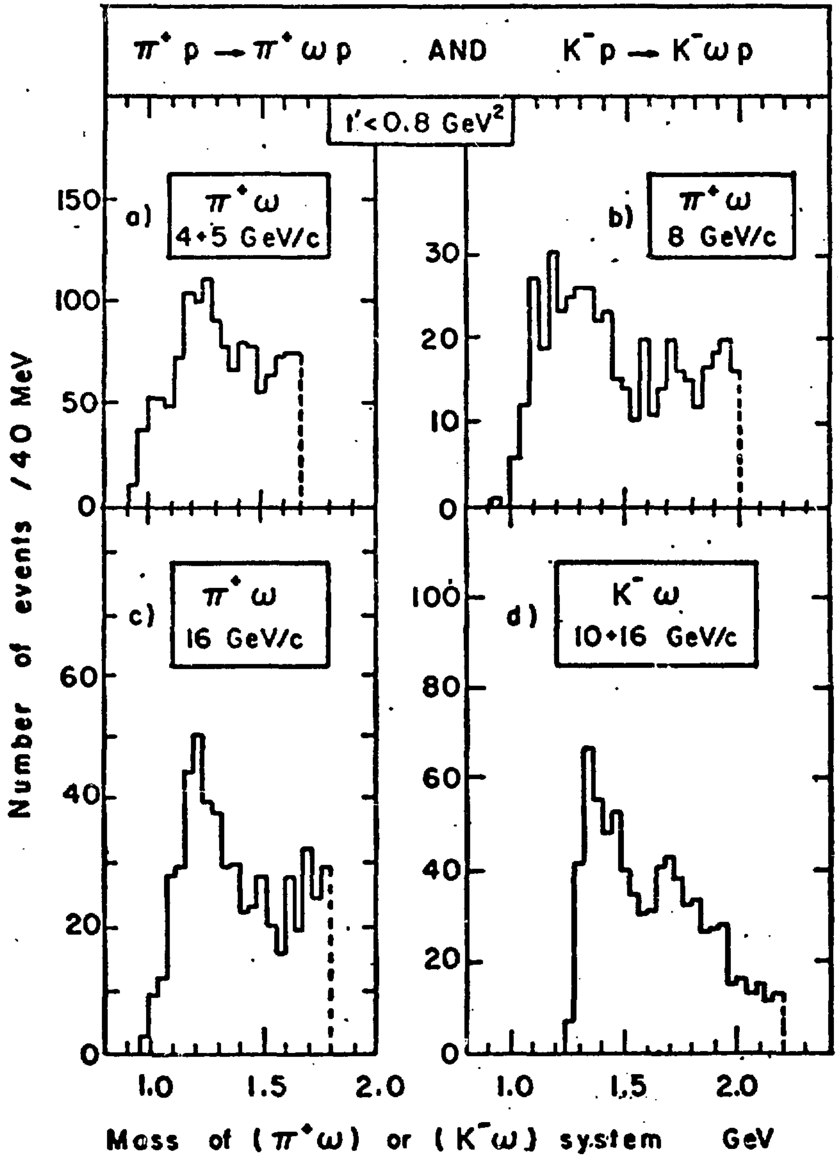
γp → p π+ π− + neutrals
0.32 < Mπ+π− < 0.6 GeV
Eγ = 2.8 GeV
Eγ = 4.7 GeV
Eγ = 9.3 GeV
(a) |t| < 0.5 GeV²
437 EVENTS
1304 EVENTS
2789 EVENTS
(b) 0.5 < |t| < 1 GeV²
396 EVENTS
809 EVENTS
1038 EVENTS
EVENTS/0.04 GeV
Mπ+π−MM (GeV)

Fig. 1



$e^+e^- \longrightarrow \pi^+ + \pi^- + \pi^0 + \pi^0$
σ (nbarn)
100
50
▲ ACO
● ADONE (I.P.S.)
1.0
1.5
2.0
GeV

Fig. 2



$\pi^+ p \to \pi^+ \omega p$ AND $K^- p \to K^- \omega p$
t' < 0.8 GeV^2
a) $\pi^+\omega$ 4+5 GeV/c
b) $\pi^+\omega$ 8 GeV/c
c) $\pi^+\omega$ 16 GeV/c
d) $K^-\omega$ 10+16 GeV/c
Number of events / 40 MeV
Mass of ($\pi^+\omega$) or ($K^-\omega$) system GeV

Fig. 3

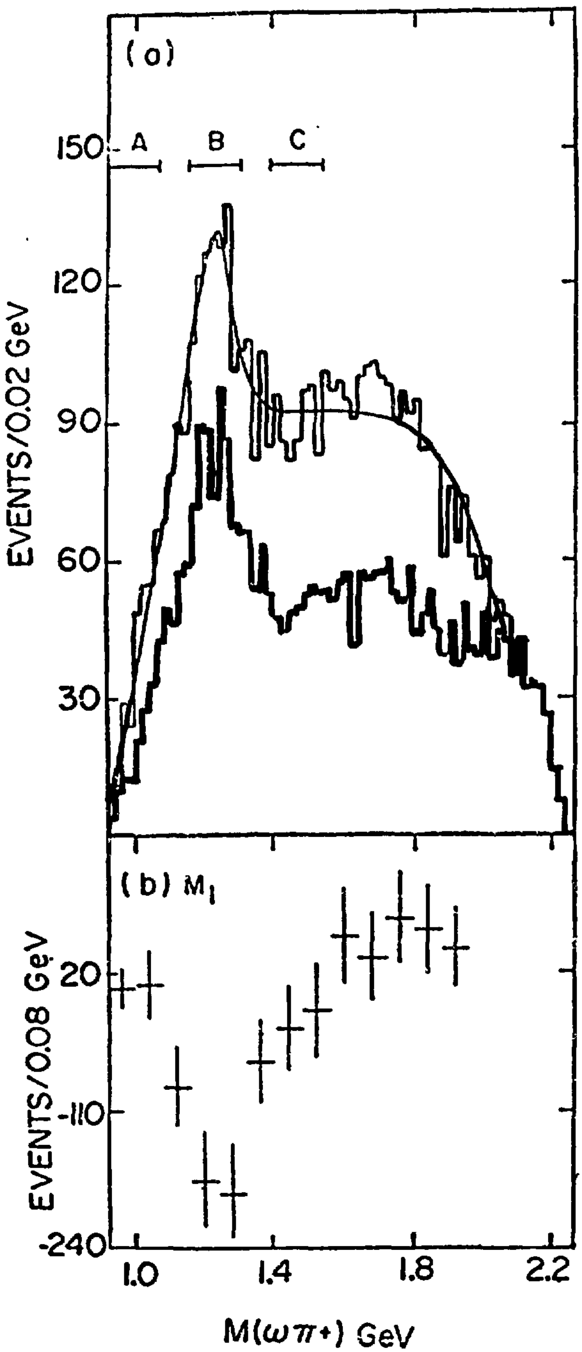
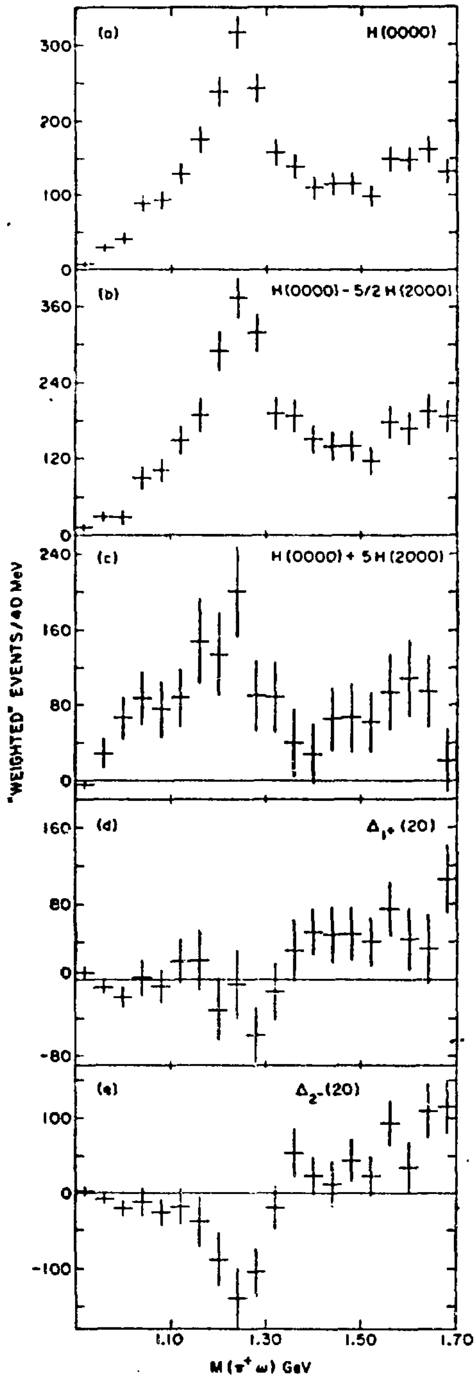
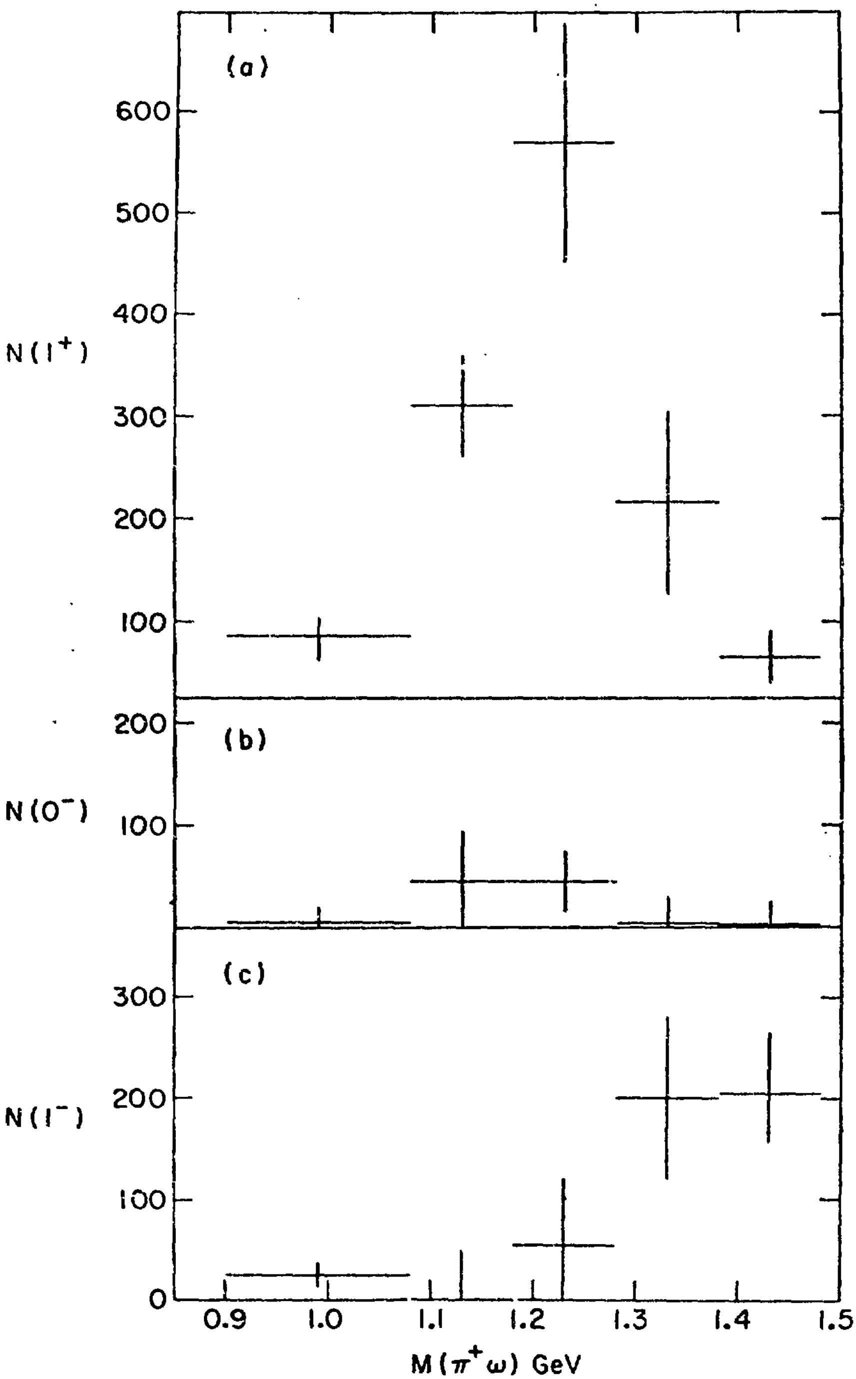

(a)
A
B
C
150
120
90
60
30
EVENTS/0.02 GeV
(b) M_1
20
-110
-240
EVENTS/0.08 GeV
1.0
1.4
1.8
2.2
M(ωπ+) GeV

Fig. 4



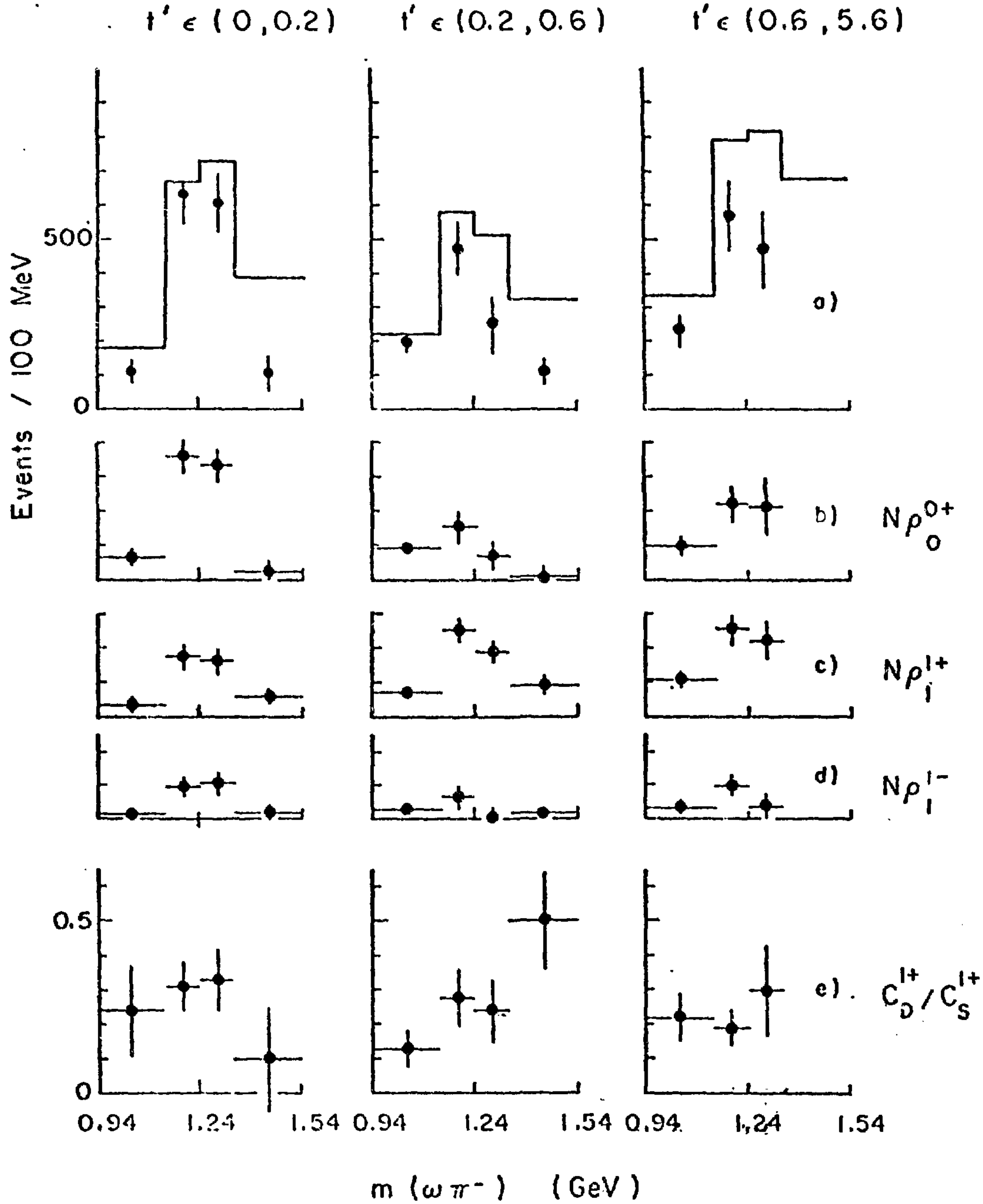
(a)
H(0000)
(b)
H(0000) - 5/2 H(2000)
(c)
H(0000) + 5H(2000)
(d)
Δ1+(20)
(e)
Δ2-(20)
"WEIGHTED" EVENTS/40 MeV
M(π+ω) GeV
1.10
1.30
1.50
1.70

Fig. 5



(a)
(b)
(c)
N(1+)
N(0−)
N(1−)
600
500
400
300
200
100
200
100
300
200
100
0
0.9
1.0
1.1
1.2
1.3
1.4
1.5
M(π+ω) GeV

Fig. 6



t' ∈ (0,0.2)
t' ∈ (0.2,0.6)
t' ∈ (0.6,5.6)
Events / 100 MeV
500
0
a)
b)
c)
d)
e)
$N\rho_0^{0+}$
$N\rho_1^{1+}$
$N\rho_1^{1-}$
C_D^{1+}/C_S^{1+}
0.5
0
0.94
1.24
1.54
m (ωπ⁻) (GeV)

Fig. 7

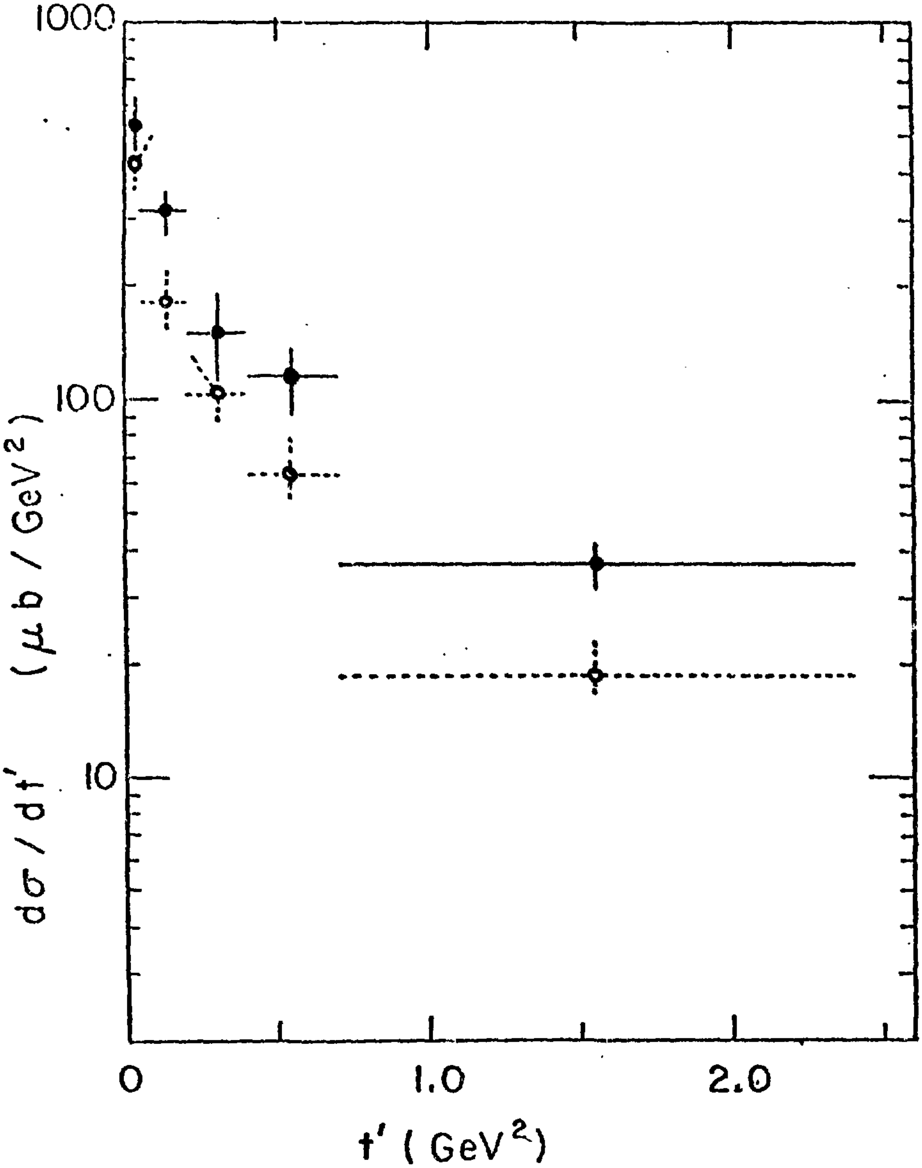


Fig. 8

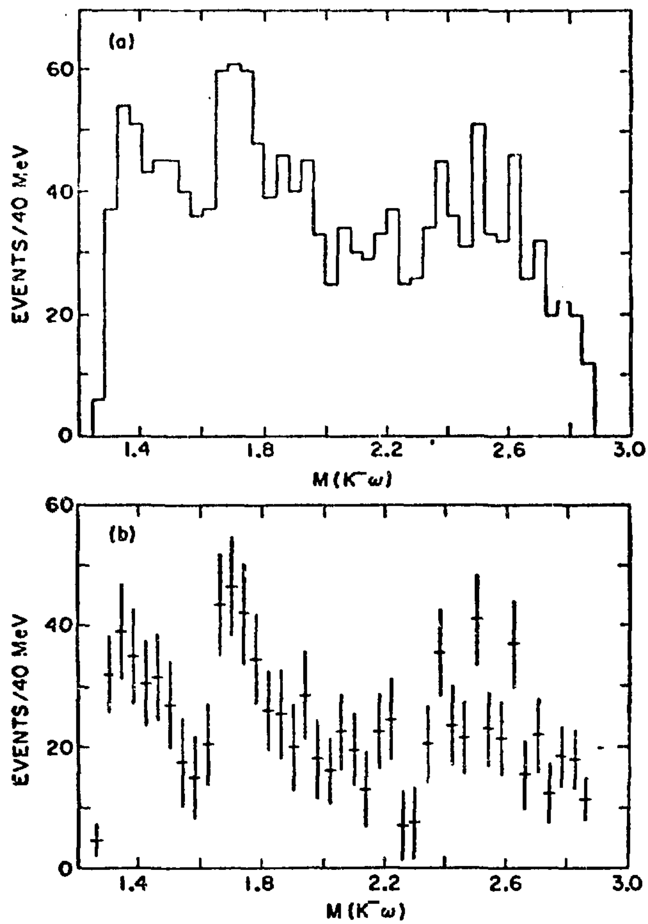
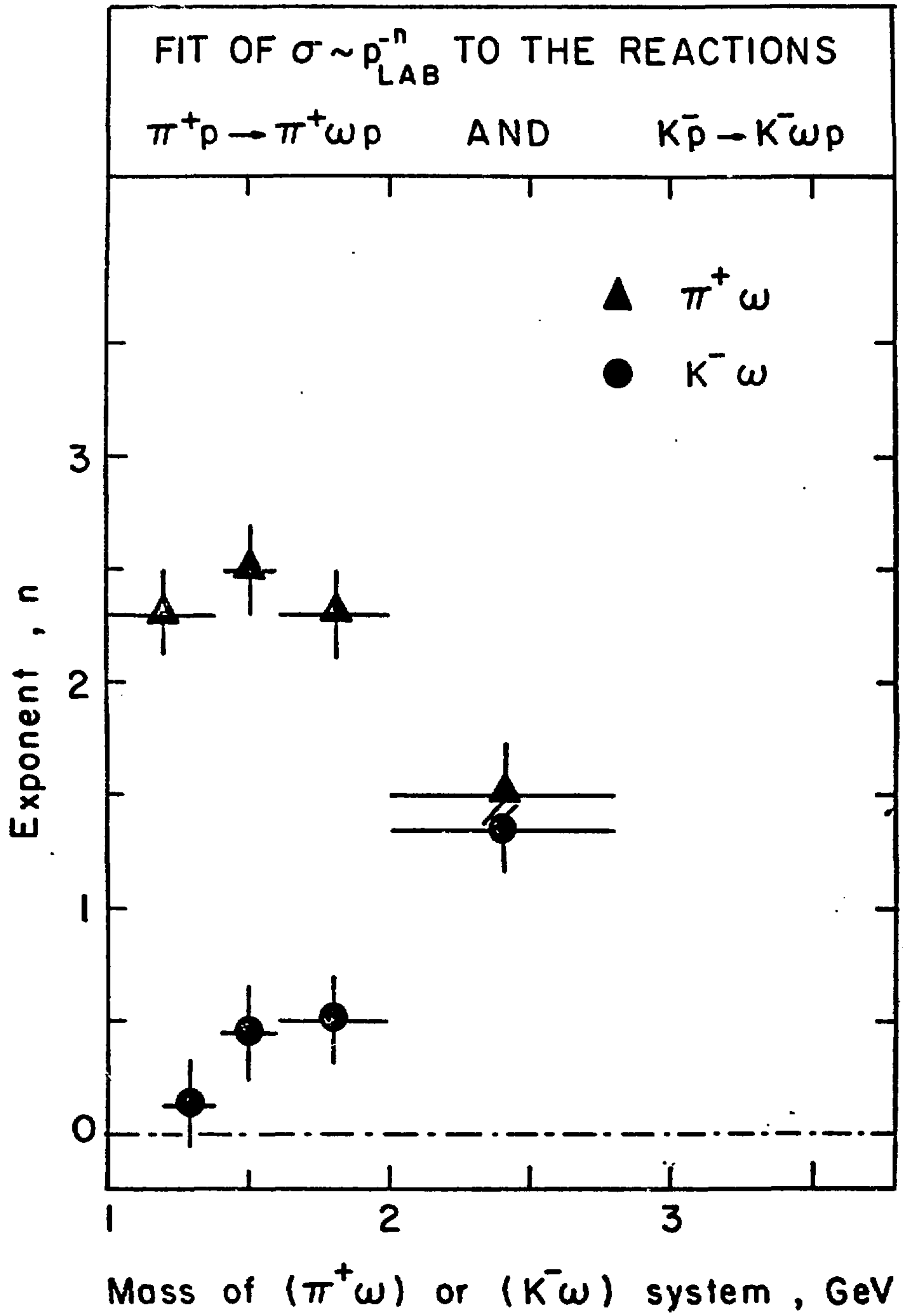

(a)
EVENTS/40 MeV
0
20
40
60
1.4
1.8
2.2
2.6
3.0
M(K⁻ω)
(b)
EVENTS/40 MeV
0
20
40
60
1.4
1.8
2.2
2.6
3.0
M(K⁻ω)

Fig. 9



FIT OF $\sigma \sim p_{LAB}^{-n}$ TO THE REACTIONS
$\pi^+ p \to \pi^+ \omega p$ AND $K^- p \to K^- \omega p$
$\pi^+ \omega$
$K^- \omega$
3
2
1
0
Exponent , n
1
2
3
Mass of $(\pi^+ \omega)$ or $(K^- \omega)$ system , GeV

Fig. 10