STUDY OF THE ω^0 MESON IN ANNIHILATIONS $\bar{p}+p\rightarrow K+\bar{K}+\omega^0$ AT REST

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(presented by A. Astier)

INTRODUCTION

The ω^0 meson has been studied in $p\bar{p}$ annihilations at rest with production of charged and neutral K mesons. The experiment was carried out in the 81 cm hydrogen bubble chamber at the CERN P.S. The branching ratio of the ω^0 decay into neutral particles and the $\pi^+\pi^-\pi^0$ mode has been measured. A value is given for the mass and limits are given for the width. The $\pi^+\pi^-\pi^0$ decay mode yields good evidence for the 1^{--} attribution of the quantum numbers. Information about the production $p\bar{p}\rightarrow K\bar{K}\omega^0$ is also given.

1. ω^0 BRANCHING RATIO INTO CHARGED AND NEUTRAL DECAY MODES (based on $K^+K^-\omega^0$ events)

This determination comes from events

$$\bar{p}+p\rightarrow K^+ + K^- + \omega^0 .$$

About 30 % of the total number of photographs have been scanned for the detection of annihilations leading to the production of at least one charged K. The identification of the $K^\pm$ was made through its decay or interaction. The second charged K was essentially identified by ionization measurements (Gap counting). In order to reduce as much as possible the contamination from annihilations in flight, only the events occurring in a well defined fiducial region of the chamber were selected for further analysis.

In Fig. 1 a the missing mass spectrum of events

$$\bar{p}+p\rightarrow K^+ + K^- + \text{missing mass} \qquad (1)$$

is shown.

In Fig. 1 b a similar spectrum is shown for events kinematically identified as due to reaction

$$\bar{p}+p\rightarrow K^+ + K^- + \pi^+ + \pi^- + \pi^0 \qquad (2)$$

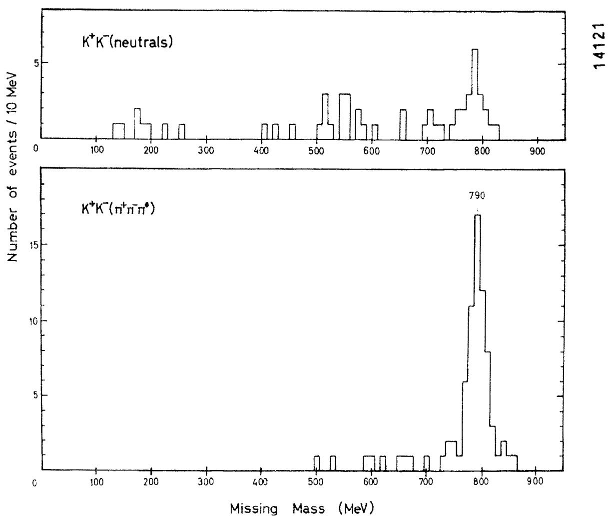

Fig. 1 a Missing mass spectrum of $\bar{p}+p\rightarrow K^+ + K^- +$ missing mass.
Fig. 1 b Missing mass spectrum of $\bar{p}+p\rightarrow K^+ + K^- + \underbrace{\pi^+ + \pi^- + \pi^0}_{\text{"missing mass"}}$

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This spectrum was obtained in exactly the same way as that for reaction (1), i.e. only the measured—as distinct from the fitted—values of the K^+K^- pair were used to calculate the mass of the $(\pi^+\pi^-\pi^0)$-system; this to allow direct comparison of the missing mass spectra in reactions (1) and (2).

Altogether we obtained 43 $(K^+K^-+\text{neutrals})$-events and 77 $(K^+K^-\pi^+\pi^-\pi^0)$-events in the missing mass range between 500 MeV and 900 MeV.

The histograms show marked peaks in the expected ω^0 mass region with a very small background contamination. The background of non-resonant events —estimated from the mean number of events per unit energy interval in the region 600 MeV $< M <$ 730 MeV —was about 0.6 events per 10 MeV interval, both in the $(K^+K^-+\text{neutrals})$-events and in the $(K^+K^-\pi^+\pi^-\pi^0)$-events.

In the resonant region (defined by 740 MeV $< M <$ 840 MeV) there remain 16.1 and 76.5 events from reactions (1) and (2) respectively. These figures are obtained after applying the following corrections: possible contamination of $(K^+K^-+\text{neutrals})$ by annihilations in flight, which can however be easily recognized for the $(K^+K^-\pi^+\pi^-\pi^0)$-events, and mainly, poor measurability and hence ambiguity in the classification of some events.

All possible measurements on the sample considered (456 events) have been completed. The events (30 events) for which no definite kinematical results have been obtained, have been classified from the available information. The events (26 events) for which some ambiguity remained have been attributed to their possible classes according to the proportions obtained in the completely defined events.

The resulting correction factor for the events in the ω^0 region is of the order of 20%.

Errors on the numbers of $(K^+K^-\pi^+\pi^-\pi^0)$ and $(K^+K^-+\text{neutrals})$ events were computed, taking into account fluctuations on the initial figures and uncertainties in the background correction and in the number of events added or substracted.

The branching ratio obtained is then:

$$\frac{\omega^0\to\text{neutrals}}{\omega^0\to\text{charged}} = \frac{16.1\pm5.2}{76.5\pm9.5} = (21\pm7.5)\%$$

Remark: The mean value of the missing masses in the ω^0 region (720 MeV $< M <$ 870 MeV) and the observed width of the distribution are:

$<M> = (789.9\pm1.6)$ MeV $\quad \sigma = 12.9$ MeV
for the $(K^+K^-\pi^+\pi^-\pi^0)$ annihilations (64 events),

$<M> = (789.3\pm3.4)$ MeV $\quad \sigma = 14.5$ MeV
for the $(K^+K^-+\text{neutrals})$ annihilations (18 events).

2. MASS AND WIDTH OF THE ω^0 (based on $K_1^0K_1^0\omega^0$ events)

We have also looked for the possible presence of the ω^0 mesons in events of the type $(K_1^0K_1^0+\text{neutrals})$ and $(K_1^0K_1^0\pi^+\pi^-\pi^0)$ in a well defined fiducial region of the chamber. In Fig. 2 the distribution of the missing mass in the $(K_1^0K_1^0+\text{neutrals})$ is shown. The data is very scanty, but a small peak appears in the ω^0 region. The estimated number of ω^0-events is about 9. It is difficult, however, to estimate the background and for this reason we do not use the $K_1^0K_1^0\omega^0$-events to establish the ω^0-branching ratio.

Fig. 3 shows the distribution of the $(\pi^+\pi^-\pi^0)$ effective mass in the $(K_1^0K_1^0\pi^+\pi^-\pi^0)$-events. Here again the peak in the ω^0 region is fairly prominent over a small background. To compute the mass of the ω^0, we take (*) all the events in the mass region between 760 MeV and 800 MeV and obtain $<M_{\omega^0}> =$ (779.4$\pm$1.4) MeV. The width of the distribution is given by $\sigma = 10$ MeV, which is consistent with our estimated experimental resolution.

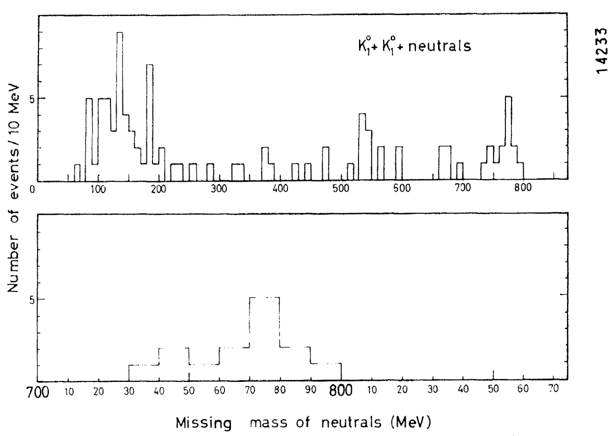

Fig. 2 Missing mass spectrum of $K_1^0+K_1^0+$neutrals.

(*) The choice of another interval, say between 750 MeV and 810 MeV, changes the mean value by only −0.4 MeV.

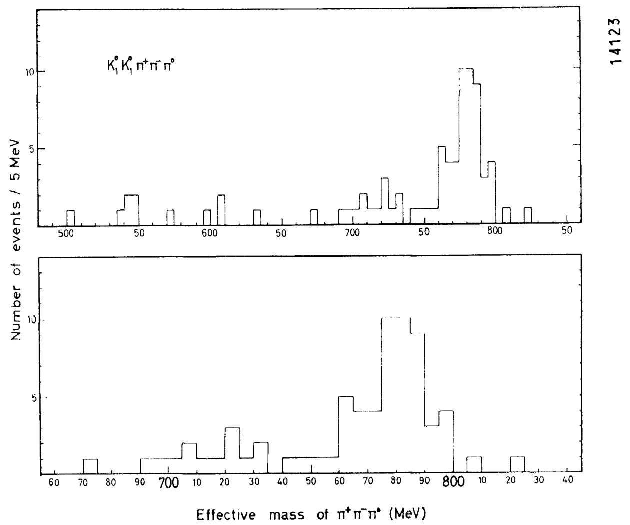

Fig. 3 Effective mass of$(\pi^+\pi^-\pi^0)$ in $p+\bar{p}\rightarrow K_1^0+K_1^0+\pi^++\pi^-+\pi^0$.

Systematic errors may distort the values given. The ω^0 mass obtained from the charged K-events is significantly higher: $<M_{\omega^0}> = (789.9\pm1.6)$ MeV. We are more confident in the mass obtained from the $K_1^0K_1^0\omega^0$ events. While the measurement of events with neutral K's is fairly straightforward, the measurement of slow charged particles depends critically on the effects of the energy loss and multiple scattering and the correct determination of the initial direction of the particle is difficult. In fact, the mass of the π^0's in events identified as $K_1^0K_1^0\pi^0$ is about 140 MeV, while the missing mass in the few $K^+K^-\pi^0$ we have observed appears to be higher (see Fig. 1).

We thus propose: $<M_{\omega^0}> = (779\pm1.4[\pm5])$ MeV, where the figure in the square brackets corresponds to the estimation of a possible systematic error.

In the same way, the best information about the natural width of the ω^0 is given by: $0\leqq\Gamma/2\leqq10$ MeV.

3. QUANTUM NUMBERS OF THE ω^0

Of the possible assignment of quantum numbers allowing a decay into 3 pions without a strong damping due to centrifugal barriers, the 1^{++} assignment should give rise to an appreciable decay rate into 4 pions [2]; this mode has been looked for but was never found [1-3]. The 0^{-+} assignment is predicted [2] to give a branching ratio $\dfrac{\omega^0\rightarrow3\pi^0}{\omega^0\rightarrow\pi^+\pi^-\pi^0}=\dfrac{3}{2}$; the results of Stevenson *et al.*[1] and our branching ratio $\dfrac{\omega^0\rightarrow\text{neutrals}}{\omega^0\rightarrow\pi^+\pi^-\pi^0}\sim20\%$ rule out this assignment.

The three remaining assignments 0^{--}, 1^{+-} and 1^{--} will now be compared with our data. The elegant treatment of the triangular Dalitz-plot introduced by Stevenson *et al.* will be used.

Fig. 4 shows the 6-folded Dalitz-plot of the 3 decay pions. The 6-folding is justified theoretically by the

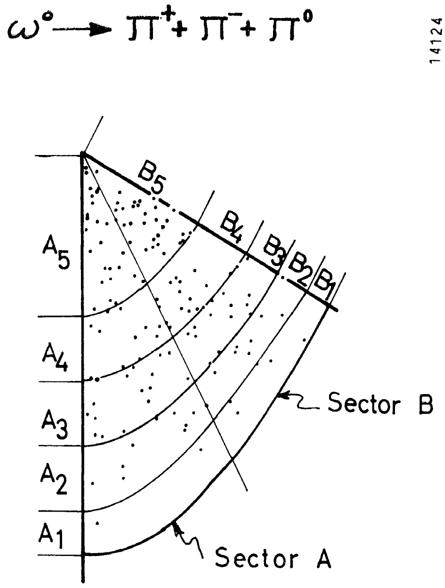

Fig. 4 Folded Dalitz plot of ω^0-decay.

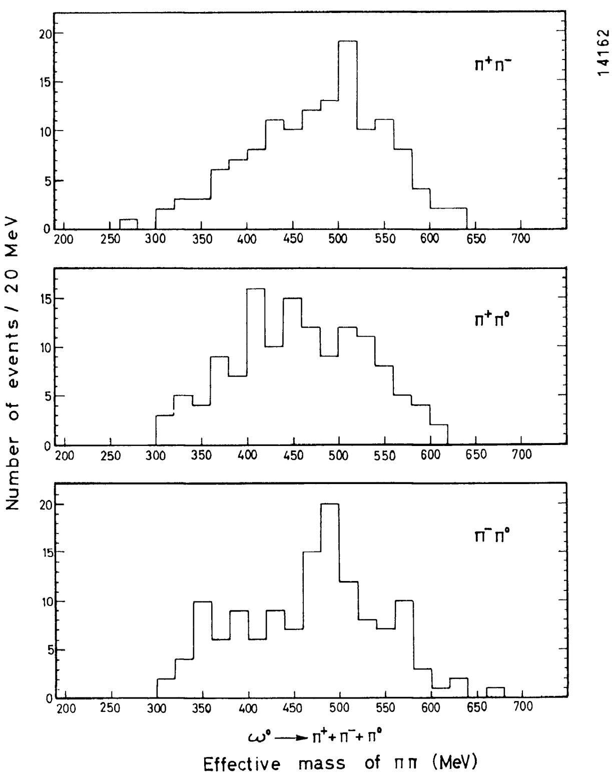

Fig. 5 Effective mass distribution of pion-pairs from ω^0-decay.

symmetry between the pions in the $I = 0$ state; this expected symmetry manifests itself in our data as we can see in Fig. 5, where the effective mass distribution of the three 2π-combinations is shown. The curves drawn on the Dalitz-plot correspond to constant value of the simplest matrix element for the assignment 1^{--}. Furthermore, the plot has been divided into two subsectors to take into account the strong azimuthal variation of the density in the 1^{+-} and 0^{--} cases. The experimental results are shown in Fig. 6 together with the curves expected for the three cases: 1^{--}, 0^{--} and 1^{+-}. The incompatibility of the experimental results with the assignment 1^{+-} and 0^{--} is obvious and, in agreement with Stevenson *et al.*, we conclude that the ω^0 is, indeed, a 1^{--} meson.

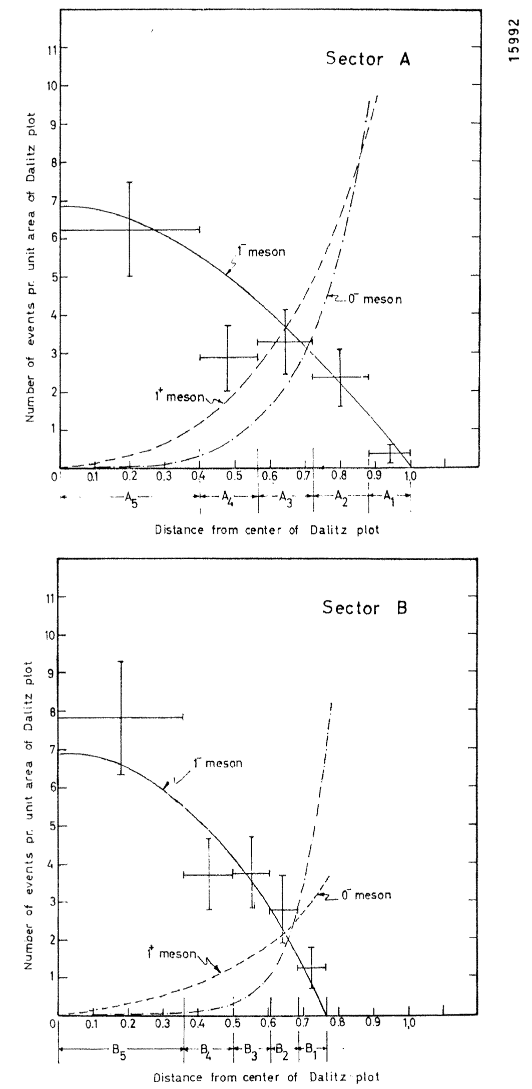

Fig. 6 Number of events per unit area in Dalitz plot of ω^0-decay plotted against the distance from the centre of the plot.

4. PRODUCTION OF ω^0 IN ANNIHILATIONS AT REST ($\bar{p}+p\to K\bar{K}\omega^0$)

In Fig. 7 we show the Dalitz-plot at production for both reactions $\bar{p}p\to K^+K^-\omega^0$ and $\bar{p}p\to K_1^0K_1^0\omega^0$ assuming—given the narrow width of the ω^0—that they can be considered as three-body reactions. The population of the Dalitz-plot does not show any

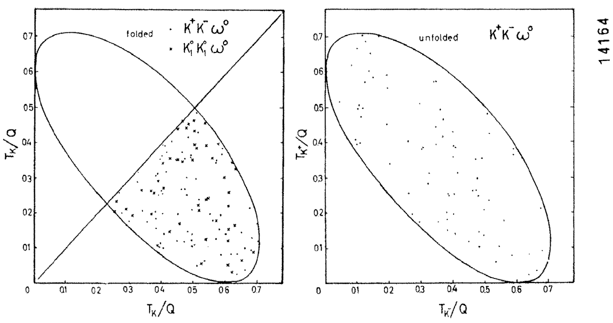

Fig. 7 Dalitz-plot of the production $\bar{p}+p\to K+\bar{K}+\omega^0$.

significant deviation from uniformity. Evidence for a $K\bar{K}$ resonance in an energy region accessible in the annihilation mode $\bar{p}+p\to K\bar{K}\omega^0$ has been presented at this Conference. The $K\bar{K}$ mass distribution shown in Fig. 8 is in agreement with the prediction of the usual covariant phase space. We see therefore no

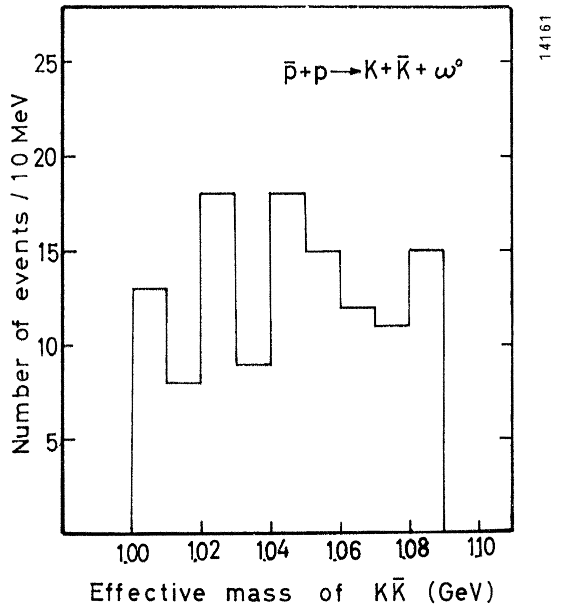

Fig. 8 Effective mass distribution of $K\bar{K}$ in $\bar{p}+p\to K+\bar{K}+\omega^0$.

narrow $K\bar{K}$ resonance in the above type of annihilation. It must be noted, however, that the range of Q-values for the system $K\bar{K}$ in this particular reaction is small ($\sim$90 MeV) and thus we cannot exclude a rather broad $K\bar{K}$ resonance. It is also interesting to remark that the (0,0) configuration must be the dominant one in the reaction we are considering [4)] and thus the occurrence of a strong $K\bar{K}$ interaction with an $l = 2$ relative orbital momentum should be inhibited by centrifugal barrier effects.

The production rate of the annihilation channel $K^+K^-\omega^0$ is estimated to be $(2.14 \pm 0.24) \cdot 10^{-3}$, where the error includes the uncertainty in the observation of the fastest $K^{\pm}$'s.

LIST OF REFERENCES

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b) M. L. Stevenson, L. W. Alvarez, B. C. Maglić and A. H. Rosenfeld, Phys. Rev., *125*, 687 (1962) and *125*, 2208 (1962).
2. H. P. Dürr and W. Heisenberg, Nuovo Cimento *23*, 807 (1962).
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4. G. A. Snow, Physics Letters, *1*, 213 (1962).

DISCUSSION

PEYROU: I have a question to ask Derrick. Since a great part of the annihilation comes from the triplet state, you expect in many cases to have energy-dependent matrix elements, especially in the 3π background. When you say phase space, have you corrected already for those matrix elements?

DERRICK: We have added incoherently to the Bouchiat-Flamand distribution a 50% background from a uniformly populated Dalitz plot. The disagreement could be due to the high energy behaviour of the $\pi\pi$ cross-section or to the unjustified treatment of the background. We feel that our statistics do not justify a fuller treatment.

SANDWEISS (to Astier): Do you see any evidence for the K^* resonance in the events in which you observe $K\bar{K}\omega$?

ASTIER: No, we have no evidence for K^* in $KK\omega^0$.

SNOW (to Astier): I would like to point out that a $J = 2$ $(K\bar{K})$, $I = 0$ resonant state can also be produced in the reaction $\bar{p}+p \rightarrow K+\bar{K}+\omega^0$ from $^3S_1$ state, consistent with charge conjugation invariance and J and parity conservation, if one assigns the quantum numbers 1^{--} to the ω. The lowest possible relative angular momentum between $(K\bar{K})$ and ω is then $l = 0$.

BREIT: If the ω-meson is the vector meson which has been speculated on in connection with the repulsive core and the spin-orbit nucleon-nucleon interaction, one would expect the simultaneous emission of an ω pair by analogy with the two-photon disintegration of positronium. For the latter there is also a smaller chance of a three-photon disintegration. It would appear significant for the vector meson hypothesis that double ω-meson emission is not observed. However, there is a difference between the two cases. The energy in the experiments reported on is high and energetically the emission of more than 2 mesons is possible. The coupling constants needed in nucleon-nucleon phenomenology for vector meson-nucleon coupling is large and hence the multiple ω-meson production should be relatively more probable than in the analogous positronium case. In this connection it would be interesting to know whether at the lower energies of the experiments reported on by Derrick there would be a possibility of finding double ω-emission.

ROSENFELD: Breit has commented that he is suprised that Sandweiss does not see $>10\%$ $\omega\bar{\omega}$ production in his 6 and 8 prongs events, because (in analogy to positronium decay) he would expect that $\bar{p}p$ should yield *pairs* of vector mesons. In addition to $\omega\bar{\omega}$ pairs one would then expect $\varrho\bar{\varrho}$ pairs and $\varrho\omega$ pairs. The latter two are much easier to find, since $\varrho\varrho$ pairs involve no missing π^0 and can be very precisely fitted. Even $\varrho\omega$ pairs involve only one missing π^0, and can still be fitted. But $\omega\omega$ pairs cannot be individually identified, as Sandweiss just pointed out. So in Berkeley last year we looked for a tendency for a ϱ to be produced in association with another ϱ or with an ω. We found no evidence that it happens at all and our experimental sensitivity was about 10%.

OMNÈS (to Snow): If one believes that the $K\bar{K}$ resonance could appear as an enhancement through the final state interaction of a primary more or less statistical process, then this primary process will produce much fewer $K\bar{K}$ pairs in a $J = 2$ state than in a $J = 0$, as follows immediately from centrifugal barrier considerations.

BREIT (to Rosenfeld): May I ask again whether you made your observations at energies that are high or low? Do you have enough energy to produce 3 ω?

ROSENFELD: The available energy in all these experiments does not vary very much, as one has first the energy available from the annihilation, which is 1.8 GeV. At Berkeley we had some extra kinetic energy which gave us a total of 2.2 GeV, and Sandweiss was working with about 2.8 GeV. The results of all three experiments just seem to show that there is no enhancement for the production of a second ϱ or ω once a ϱ is produced; only Yale can produce $3\omega+500$ MeV excess Q.

SANDWEISS: We also looked at the ϱ's that were made in our 4π annihilations and they are all uniformly made alone, i.e. there are no events beyond what would be predicted by phase space. The question I would like to ask is: has the analysis for ω pairs been made in the other anti-proton experiments?

DERRICK: We have not done this yet, but we plan to do it in the future.

EISENBERG: Can the previous speakers give us any upper limit for the η production in $\bar{p}p$ annihilation?

DERRICK: We observed a very small peak in the mass region of the η, but the number of events is so small that we really cannot say anything.

ASTIER: We have observed no pronounced peaks in the expected mass region for the η^0, neither in the reaction $\bar{p}+p \rightarrow K+\bar{K}+$neutrals nor in $\bar{p}+p \rightarrow K+\bar{K}+\pi^+ + \pi^- + \pi^0$.

STEINER (to Sandweiss): I would like to ask whether you can set a limit on the annihilation into 2 particles only, 2 π or 2 K, especially $2K_1{}^0$?

SANDWEISS: I do not believe any of our events are consistent with 2π or $2K$ final states, but I cannot quote a number just now for the upper limit.

STEINBERGER (to Astier): I would like to ask whether you have observed events with 2 stopping K's and an ω? These events should be very good for the measurement of the width of the ω, because of the good resolution which can be obtained.

ASTIER: We have a small number of $K^+K^-\omega^0$ events with 2 stopping charged K's. The determination of the ω^0 mass from these events is not as accurate as from the $K_1{}^0K_1{}^0\omega^0$ events, mainly because of the inaccuracy in our present determination of the $K^\pm$ direction.

MORRISON (to Steiner): At CERN we have looked at some 50,000 photographs of 3 GeV anti-protons, particularly looking for large angle elastic scatters. At the same time we automatically studied any annihilation leading to 2 charged pions or 2 charged kaons and did not find any example of this. This gives an upper limit for these cross-sections of the order of a few microbarns.

ROSENFELD (to Derrick): I would like to point out that it is not so surprising that one does not see any η^0 on your slide which shows the production of ω^0's. There are about 100 ω^0 in the peak. If the spin of the η is zero, then there is some spin multiplicity against it, which may reduce it to about $^1/_3$. Furthermore, the η decays only in about $^1/_4$ of the cases in the charged mode which you have studied, so all this adds up to about a factor of 10. So one would expect to see about 10η. What one sees is probably less, but the discrepancy is certainly not an order of magnitude.

PEYROU: I would like to come back to the absence of a $K\bar{K}$ resonance in the $K\bar{K}\omega$ events. In many cases where two resonant states could be produced independently it happens only rarely. One does not observe many $\varrho-\varrho$, $\omega-\varrho$ or $\omega-\omega$ productions, K^*-K^* might also not be too copious. This is, of course, not a general rule and contrary examples have been observed. Nevertheless one should bear it in mind before thinking that the absence of a $K-\bar{K}$ peak in the $K\bar{K}\omega$ annihilation mode is a strong argument against the existence of a $K-\bar{K}$ resonance.

SNOW: For the 0^{-+} assignment to the η, one expects dominant $K\bar{K}\eta$ production from the $^1S_0$ rather than from the $^3S_1$ state, using angular momentum barrier arguments plus J, parity and C conservation rules. This could introduce a factor of 3 suppression in η production relative to ω production, which is favoured to come from the $^3S_1$ state. This factor of 3 might help to explain the low yield of η's in the $\bar{p}p \rightarrow K\bar{K}\eta$ reaction.