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EVIDENCE FOR THE $B\pi$ DECAY MODE OF THE $\omega(1670)$

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ABSTRACT

Backward production of $\omega(1670)$ is observed in the reactions
 $K^-p \rightarrow \pi^+\pi^-\omega^0\Lambda^0$ and $K^-p \rightarrow \pi^+\pi^-\pi^0\Lambda^0$ for $|U_\Lambda| < 1.0 \text{ GeV}^2$. The cross section
for the $\omega(1670) \rightarrow \pi^+\pi^-\omega^0$ decay mode is $1.90 \pm 0.35 \text{ } \mu\text{b}$ for 8.25 GeV/c
incident K^- . Evidence is presented for the importance of the sequential
decay, $\omega(1670) \rightarrow B\pi \rightarrow \omega\pi\pi$ with a branching ratio

$$\omega(1670) \rightarrow B\pi / \text{all } \omega(1670) \rightarrow \omega\pi\pi = 1.0 \pm {}^{0:00}_{0:25}.$$

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Knowledge of the properties of $\omega(1670)$ is obtained mainly from partial wave analyses of the $\pi^+\pi^-\pi^0$ state observed in $\pi^\pm$ induced reactions [1] and in one K^-p experiment at 4.2 GeV/c [2]. Little is known about the possible $\omega\pi\pi$ decay mode [3].

This paper is mainly devoted to the properties of the $\omega\pi\pi$ decay mode, although the $\pi^-\pi^+\pi^0$ decay mode is also observed. The data represent about half of a 5×10^6 picture exposure of the CERN 2m HBC to a separated beam of 8.25 GeV/c K^- mesons, currently giving a sensitivity of about 100 events/ μb .

The reactions considered are

$$K^-p \rightarrow \pi^-\pi^+\omega^0\Lambda \quad (1)$$

and

$$K^-p \rightarrow \pi^-\pi^+\pi^0\Lambda \quad (2)$$

The sample of events for reaction (1) are obtained from the channel

$$K^-p \rightarrow \pi^-\pi^+\pi^-\pi^+\pi^0\Lambda \quad (3)$$

by requiring $0.745 < M(\pi^+\pi^-\pi^0) < 0.82$ GeV for at least one of the four possible combinations. Background under the ω^0 peak results in $\sim 40\%$ contamination of non ω^0 events in the sample. In both reactions (1) and (2), evidence of $\omega(1670)$ production is seen in the mass spectra for backward production only, defined in all the data presented here by $|U'_\Lambda| < 1.0$ GeV².

With this backward cut, reaction (1) shows a peak in the $\pi^-\pi^+\omega^0$ effective mass spectrum at 1.68 GeV. However, the background can be significantly reduced without reduction of the signal by cutting out the strong $\Sigma^\pm(1385)$ signals using the cut $1.32 < M(\Lambda\pi^\pm) < 1.44$ GeV. The resulting mass distribution is shown in fig. 1(a). The peak at 1.68 GeV represents a 4σ signal above a fit using a fourth order polynomial alone over the mass range 1.24 - 2.64 GeV. The curves shown represent a fit to resonance plus background (linear background is found sufficient over the region fitted). This fit gives the peak a significance of $\sim 6\sigma$ and the results

$$M = 1.685 \pm 0.020 \text{ GeV}, \quad \Gamma = 0.160 \pm 0.050 \text{ GeV}$$

and after correction for unseen decay modes and losses

$$\sigma(K^- p \rightarrow \Lambda + \omega(1670)) = 1.90 \pm 0.35 \text{ } \mu\text{b} \text{ for } |U'_\Lambda| < 1.0 \text{ GeV}^2.$$

$\downarrow$
 $\omega\pi\pi$

The mass and width are consistent with the accepted values for $\omega(1670)$ [4]. An ω^0 side-band selection, requiring $0.62 < M(\pi^+\pi^-\pi^0) < 0.94 \text{ GeV}$ for at least one of the combinations, but excluding events already appearing in fig. 1(a), gives a $M(5\pi)$ distribution (not shown) which exhibits no peaks, thus verifying that the peak observed in fig. 1(a) is indeed due to the $\pi^+\pi^-\omega^0$ state.

Having established the existence of a signal at 1.68 GeV in the $\omega\pi^+\pi^-$ state, we now turn briefly to consider the $\pi^+\pi^-\pi^0$ state of channel (2). Since the $\omega(1670)$ is best established in the $\rho\pi$ (or $\pi^+\pi^-\pi^0$) decay mode [4], we wish to verify the existence of this decay mode in our data in order to further substantiate the identification of the $\pi^+\pi^-\omega^0$ peak with the $\omega(1670)$. In reaction (2) we also remove the strong $\Sigma^\pm(1385)$ signals and, additionally, the $\Sigma^0(1385)$ ($1.32 < M(\Lambda\pi^0) < 1.48 \text{ GeV}$). The resulting $\pi^+\pi^-\pi^0$ effective mass distribution is shown in fig. 1(b). The rapid rise near 1.0 GeV is presumably due to the presence of resonant states, which makes the determination of background level difficult. Fits have therefore been made to the mass spectrum above 1.04 GeV assuming a linear background. The fits are not dependent on the precise $|U'|$ and Y^* cuts used and give the results

$$M = 1.660 \pm .025 \text{ GeV} \quad \Gamma = 0.150 \pm 0.070 \text{ GeV}$$

and show that essentially all the signal occurs at $|U'_\Lambda| < 1.0 \text{ GeV}^2$ as also found for the $\omega\pi\pi$ signal. We estimate

$$\sigma(K^- p \rightarrow \Lambda + \omega(1670) \rightarrow \pi^+\pi^-\pi^0) = 2.25 \pm \begin{matrix} 1.20 \\ 0.60 \end{matrix} \text{ } \mu\text{b} ,$$

$\downarrow$
 $\pi^+\pi^-\pi^0$

where the asymmetric errors represent an allowance for the uncertainty of background level.

It is known that the $\pi^+\pi^-\pi^0$ decay mode of $\omega(1670)$ contains a large component of $\rho\pi$ [4]. In our data we can say nothing about $\rho^\pm\pi^\mp$ because of the large amount of $\rho^\pm$ in the background. However, we find $\sim 2\sigma$ excess of $\rho^0\pi^0$ in the resonance region compared to neighbouring regions, weak evidence for the $\rho\pi$ decay mode and $I = 0$ for this enhancement.

Our observations are consistent with established properties of the 3π decay mode of the $\omega(1670)$. Since the properties we observe for the $\pi^+\pi^-\pi^0$ and $\pi^+\pi^-\omega^0$ enhancements also agree, we conclude that we are observing the $\pi^+\pi^-\omega^0$ decay mode of the $\omega(1670)$.

For the remainder of this paper we return to the study of the $\pi^+\pi^-\omega^0$ decay mode of the $\omega(1670)$. We make no attempt to determine the spin-parity from this decay mode because of the limited statistics. Assuming the results $J^P = 3^-$ obtained from partial wave analyses of the $\pi^+\pi^-\pi^0$ state [1], we examine the question of whether there is significant decay of $\omega(1670)$ via an intermediate $B^\pm\pi^\mp$ state as has been suggested by SU_3 analysis of meson decay systematics [5].

Fig. 1(c) shows the combined $\omega\pi^+$ and $\omega\pi^-$ effective mass distributions for reaction (1). A clear peak is seen at 1.20 GeV which we identify with the B meson. The contributions of B^+ and B^- to the peak of fig. 1(c) are consistent with being equal. A fit to the mass spectrum, using an S-wave Breit-Wigner resonance shape and a polynomial background shape gives a total of $130 \pm 20 B^\pm$ combinations with

$$M = 1.200 \pm .011 \text{ GeV}, \Gamma = 0.122 \pm .053.$$

The observed mass is somewhat lower than the usually accepted value [4] ($1.230 \pm .010$) and will be commented on below.

The shaded region of fig. 1(c) shows the $M(\pi^\pm\omega)$ distribution for events with $M(\pi\pi\omega) > 2.0$ GeV in which the estimated $B^\pm$ signal is 10 ± 10 events. Thus essentially all $B^\pm$ signal comes from the $M(\pi\pi\omega)$ region where the $\omega(1670)$ is observed. If $B\pi$ background is distributed according to phase space we would expect only $\sim 5 \pm 5 B^\pm$ events in the non-resonant background for $M(\pi\pi\omega) < 2.0$ GeV. Even if this estimate is considerably exceeded, a large part of the $B^\pm$ signal must arise from the $\omega(1670)$.

Evidence for this is shown in fig. 2 where a B band selection (fig. 2(a)), centred at 1.2 GeV, shows a much larger $\omega(1670)$ peak than the side-band selection of fig. 2(b). In addition, fits have been performed to determine the relationship between $B^\pm$ intensity and $M(\omega\pi\pi)$. In these fits, events in various $M(\omega\pi\pi)$ intervals have been removed and the $M(\pi^\pm\omega)$ spectra for the remaining events fitted. The effect of such cuts on the background distributions was studied by Monte-Carlo simulation. These fits show the $B^\pm$ signal to peak in the $\omega(1670)$ mass region with 88 ± 20 combinations for $1.56 < M(\pi\pi\omega) < 1.76$ GeV. This amount of $B^\pm$ is too great to arise from the estimated ~ 15 background events in this $M(\pi\pi\omega)$ region.

The only reasonable interpretation of the above points is that the $B^\pm$ signal arises mainly from the $\omega(1670)$ decay. The number of $B^\pm$ events observed then indicates that the $\omega(1670) \rightarrow \omega\pi^+\pi^-$ decay occurs largely via the $B^\pm\pi^\mp$ intermediate state.

We now examine whether other features of the data are consistent with this interpretation. Fig. 3(a) shows the $\pi^+\pi^-\omega$ Dalitz plot for the $\omega(1670)$ region ($1.56 < M(\omega\pi^+\pi^-) < 1.76$ GeV). A significant enhancement of plot density occurs in the region where the B^+ and B^- bands overlap. Neighbouring regions of $M(\omega\pi^+\pi^-)$, for which the kinematically allowed $B^\pm$ overlap region is reduced, have an almost uniform distribution (not shown). An $I = 0$ resonance with $J^P = 3^-$ decaying via $B^\pm\pi^\mp$ gives a simple explanation of the behaviour in the resonance region. A comparison with Monte-Carlo generated events for $\omega(1670)$ and background shows our data to be consistent with a 100% $B^\pm\pi^\mp$ decay mode for the $\omega(1670)$ in the $\omega\pi^+\pi^-$ channel. The Dalitz plot density of the resonance has been calculated using the tensor methods of Zemach [6], with the correct helicity structure for the $B \rightarrow \pi\omega$ decay included and assuming the $\omega(1670) \rightarrow B\pi$ decay to be entirely d-wave. Background is generated with a uniform Dalitz plot distribution. The relative amounts of resonance and background included are as determined by the fit to fig. 1(a).

This model reproduces the observed enhancement in the $B^\pm$ overlap region (fig. 3(b)) and also produces a $B^\pm$ peak shifted to lower mass by the interference effect between $B^+\pi^-$ and $B^-\pi^+$ predicted by the symmetrised

amplitude. In figs 1(c) and 2 the solid curves show the model predictions which are in good agreement with the data. In fig. 1(c) the shift in mass of the $B^\pm$ peak is well reproduced as is also the relative amount of $B^\pm$ and background. Fig. 3(c) shows the cosine of the $\pi\pi$ helicity angle for $1.56 < M(\omega\pi\pi) < 1.76$ GeV (the direction of π^+ relative to ω^0 measured in the $\pi\pi$ rest frame) with the solid curve indicating the prediction of the model. The agreement between the data and model shows that the $\omega(1670) \rightarrow \omega\pi\pi$ decay is consistent with 100% occurrence via the $B\pi$ intermediate state.

An $\omega(1670) \rightarrow \omega\pi\pi$ decay mode in which the B plays no role, however, would also lead to a peak in the $\pi\omega$ mass spectrum near 1.2 GeV due to kinematic effects. We have therefore also considered a model for the $\omega\pi^+\pi^-$ decay mode of the $\omega(1670)$ which does not involve a $B\pi$ intermediate state. This model has been chosen to give the best possible fit to the Dalitz plot distribution for $1.56 < M(\omega\pi\pi) < 1.76$ GeV. The result consists mainly of an $L = 0, \ell = 2$ amplitude, with a small contribution of an $L = 2, \ell = 0$ amplitude, where ℓ is the relative angular momentum of the pions and L the angular momentum between the ω^0 and dipion. This model does not fit the $\pi\pi$ helicity angular distribution well and gives a broad kinematic enhancement in the total $M(\pi^\pm\omega)$ spectrum, as shown by the dashed curves of figs 3(c) and 1(c) respectively. In fig. 1(c) a χ^2 fit probability of 0.003 is obtained for the region of the enhancement, compared to 0.25 for the $B^\pm\pi^\mp$ model. We therefore conclude that the $M(\omega\pi^\pm)$ peak observed in fig. 1(c) cannot be attributed to a purely kinematic origin. Furthermore, if fits are made to the total $M(\pi^\pm\omega)$ spectrum (fig. 1(c)) or to the $\pi\pi$ helicity distribution (fig. 3(c)) using a combination of the above two models (ignoring interference) the best fit requires the decay $\omega(1670) \rightarrow \omega\pi\pi$ to occur 100% through an intermediate $B\pi$ state and gives the result

$$R \left(\frac{\omega(1670) \rightarrow B^\pm \pi^\mp}{\text{all } \omega(1670) \rightarrow \omega\pi^+\pi^-} \right) = 1.0 \pm \begin{matrix} 0.0 \\ 0.25 \end{matrix} .$$

This result assumes negligible $B^\pm$ contribution to the background, which, as shown above, is indicated by the data. Only half of the background

under the $\omega(1670)$ consists of true $\pi\pi\omega$ events. Under the extreme assumption that each $\pi\pi\omega$ background event contains a B, the above ratio would be lowered by no more than 10%.

In conclusion, we have observed the first example of backward production of the $\omega(1670)$. In the reaction studied here, $K^-p \rightarrow \Lambda^0\omega(1670)$, only $I = \frac{1}{2}$ exchanges are permitted, and presumably production occurs via nucleon exchange. Furthermore, as well as the $\pi^+\pi^-\pi^0$ decay mode we have observed definite evidence for the existence of the $\pi^+\pi^-\omega^0$ decay mode. Finally, we have shown strong evidence for a significant $B^{\pm}\pi^{\mp}$ decay mode in the $\pi^+\pi^-\omega^0$ channel.

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FIGURE CAPTIONS

- Fig. 1 (a) The $\pi^+\pi^-\omega^0$ effective mass distribution for reaction (1) with $\Sigma^\pm(1385)$ removed and $|U'_\Lambda| < 1 \text{ GeV}^2$.
- (b) The $\pi^+\pi^-\pi^0$ effective mass distribution for reaction (2) with $\Sigma^{\pm,0}(1385)$ removed and $|U'_\Lambda| < 1 \text{ GeV}^2$.
- (c) The sum of $\pi^+\omega$ and $\pi^-\omega$ effective mass distributions corresponding to the data of (a). The shaded region shows the events for $M(\omega\pi\pi) > 2.0 \text{ GeV}$. The curves indicate the predictions of models described in the text.
- Fig. 2 (a) $M(\pi^+\pi^-\omega)$ distribution for events in the $B^\pm$ regions $1.08 < M(\pi^\pm\omega) < 1.32 \text{ GeV}$.
- (b) $M(\pi^+\pi^-\omega)$ for events in $B^\pm$ side-bands defined by $0.8 < M(\pi^\pm\omega) < 1.08$ and $1.32 < M(\pi^\pm\omega) < 1.48 \text{ GeV}$. The curves are described in the text.
- Fig. 3 (a) The Dalitz plot for events in the $\omega(1670)$ region from reaction (1). Dotted lines indicate the position of the $B^\pm$ bands. The Dalitz plot boundaries correspond to $M(\omega\pi\pi)$ of 1.56 and 1.76 GeV respectively.
- (b) The same for Monte-Carlo generated events ($\times 10$) assuming the $\omega\pi\pi$ decay mode of the $\omega(1670)$ proceeds entirely via the $B\pi$ intermediate state.
- (c) $\pi\pi$ helicity angle as defined in text for $\omega(1670)$ region. The curves indicate the predictions of models described in the text.

Fig. 1

COMBINATIONS/40 MeV

Fig. 2

Fig. 3