A study of the $\omega\eta$ system produced in the reaction $\pi^- p \rightarrow \pi^+\pi^- 4\gamma\ n$ at 18 GeV/c

Paul Eugenio
for the Brookhaven E852 Collaboration*
Carnegie Mellon University
Pittsburgh, PA 15213, USA

Results are presented on a study of structure in the $\omega\eta$ final state produced in $\pi^- p$ interactions at 18 GeV/c where $\omega \rightarrow \pi^+\pi^-\pi^0$, $\pi^0 \rightarrow 2\gamma$, and $\eta \rightarrow 2\gamma$. In the extended flux tube model, the $\omega\eta$ decay of an isoscalar $J^{PC} = 1^{--}$ hybrid meson is expected. The observed $\omega\eta$ invariant mass distribution rises rapidly from threshold but in general shows no obvious indication of resonant structure. However the result of a partial wave analysis finds both a $J^{PC} = 1^{--}$ signal consistent with the previously observed $\omega(1600)$ and a dominant $J^{PC} = 1^{+-}$ partial wave which exhibits phase motion relative to the $\omega(1600)$. The decay $\omega(1600) \rightarrow \omega\eta$ has not been previously reported.

1. INTRODUCTION

Experiment E852 at Brookhaven National Laboratory is an experiment in meson spectroscopy with a focus on studying both neutral and charged final states of $\pi^- p$ collisions in a search for meson states incompatible with the constituent quark model. (A description of Brookhaven E852 is given in these proceedings[1].). An analysis effort of the E852 data is currently underway which studies the $\omega\eta$ system produced in the reaction $\pi^- p \rightarrow \pi^+\pi^-\pi^0\eta n$. A total of 750 million triggers were acquired during the 1995 data run of which 108 million were of a type designed to enrich the exclusive final state events $\pi^- p \rightarrow n\pi^+\pi^- 4\gamma$. A total of 6 million events of this type were fully reconstructed. The data were kinematically fitted to select events consistent with an $n\pi^+\pi^-\pi^0\eta$ hypothesis. To eliminate incorrectly hypothesized events a minimum acceptable confidence level was set to 10%.

One problem in interpreting the results of the kinematic fit is deciding between hypotheses for ambiguous events. There are six ways to combine the 4 γ into pairs. Twenty-nine percent of the fitted $n\pi^+\pi^-\pi^0\eta$ events were also found to fit to an $n\pi^+\pi^-\pi^0\pi^0$ hypothesis. Events with this ambiguity were removed from the data. A total of 113000 $n\pi^+\pi^-\pi^0\eta$ events remained for further analysis.

Two prominent resonances are seen in the $\pi^+\pi^-\pi^0$ invariant mass distribution(see Figure 1a). These are the well known η and the ω. In Figure 1b, the $\omega\eta$ invariant mass distribution of 19530 $\omega\eta$ final state events is shown. The ω selection is 750 MeV/c^2 $\leq$

*The E852 Collaboration authors are listed in the contribution to this conference by P. Eugenio, titled *Meson Spectroscopy in $\pi^- p$ Interactions at 18 GeV/c –Recent Results from Brookhaven E852.*

Mass[3π] $\leq$ 830 MeV/c^2. The invariant mass distribution rises rapidly near threshold, then increases at a slower rate to a maximum near 1600 MeV/c^2. The strong threshold enhancement might be explained by a state being produced near the $\omega\eta$ mass threshold. However, the mass distribution shows no clear evidence for structures indicating the presence of resonant states.

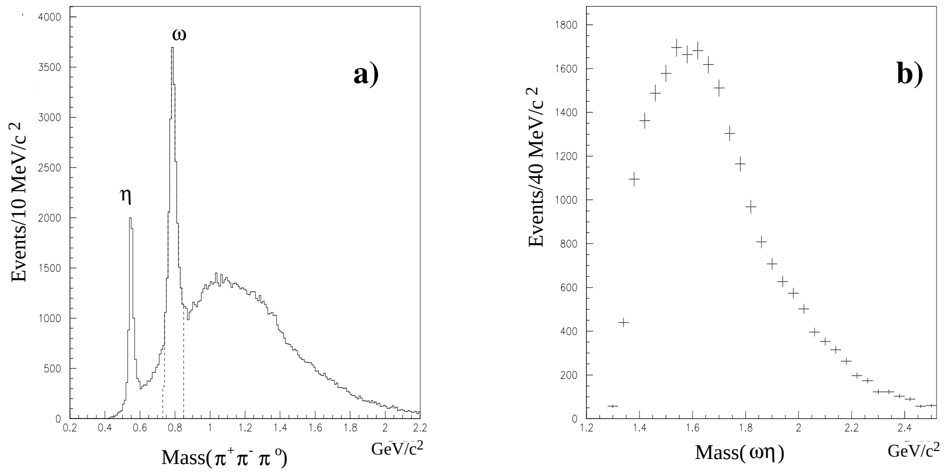

Figure 1. [a] The $\pi^+\pi^-\pi^0$ effective mass distribution. [b] The $\omega\eta$ effective mass distribution.

2. PARTIAL WAVE ANALYSIS

The data used in the partial wave analysis (PWA) are shown in Figure 1b. Typically there are 1000 events per 40 MeV/c^2 mass bin. A rank 2 fit was performed in twenty overlapping 80 MeV/c^2 wide mass bins at 40 MeV/c^2 intervals from 1340 to 2200 MeV/c^2 and in the t region: $0 \leq |t| \leq 1.2$ (GeV/c^2)^2. All partial waves for $L < 4$ and $M < 2$ were considered in this analysis. The partial waves $J^{PC}M^{\epsilon}L$ are expressed in the reflectivity basis which takes into account parity conservation in the production process by a transformation of helicity states to eigenstates of the reflection operator in the production plane[2]. Amplitudes of different reflectivity, $\epsilon = \pm$, do not interfere.

The most significant partial waves found in the analysis are the $1^{+-}0^{+}S$ and $1^{--}1^{+}P$ waves. The contributions of the $2^{+-}, 3^{--}, 3^{+-}$ and 4^{--} are considerably smaller and relatively featureless. These waves tend to become more important at masses higher than 1700 MeV/c^2, and the partial waves contributing to the 2^{--} intensity have large errorbars and do not have any obvious structure. It is important to note that the exotic waves ($J^{PC} = 0^{--}, 2^{+-}$) do not show any clear resonant-like structures.

The only reported isoscalar $J^{PC} = 1^{+-}$ states are the $h_1(1160)$ and $h_1'(1380)$[3], and both of these states have masses much lower than the observed structure in the $1^{+-}0^{+}S$ wave. There are two isoscalar $J^{PC} = 1^{--}$ states listed between the 1000-2000 MeV/c^2 range in the PDG[3]. These are the the $\omega(1420)$ and the $\omega(1600)$. The mass and width of the $\omega(1600)$ (1649 ± 24 MeV/c^2 and 222 ± 35 MeV/c^2 respectively) are in good agreement with the observed structure in the $1^{--}1^{+}P$ wave.

The absolute sign of the relative phase between waves for the $\omega\eta$ system is unknown. This leads to two ambiguous solutions which result in the same partial wave intensities, but with a relative phase of opposite sign. Figure 2 shows the phase difference for both solutions between the $1^{--}1^{-}P$ and $1^{+-}0^{-}S$ waves. The physical interpretation of the $1^{--}1^{-}P$ and $1^{+-}0^{-}S$ waves is made more difficult by a crossing over at zero of the relative phases for the two solutions in the region of 1450 MeV/c^2. These ambiguities lead to 4 possible phase motions: [1] a relative phase $\phi_{1^{+-}0^{+}S} - \phi_{1^{--}1^{+}P}$ always positive, [2] a relative phase $\phi_{1^{+-}0^{+}S} - \phi_{1^{--}1^{+}P}$ always negative, [3] a relative phase $\phi_{1^{+-}0^{+}S} - \phi_{1^{--}1^{+}P}$ positive at low mass changing negative at high mass, and [4] a relative phase $\phi_{1^{+-}0^{+}S} - \phi_{1^{--}1^{+}P}$ negative at low mass changing positive at high mass.

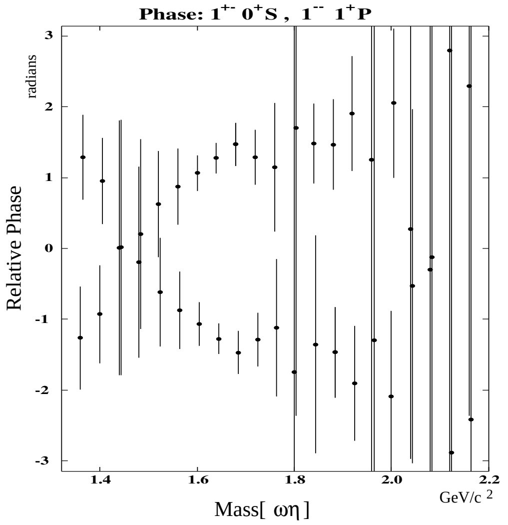

Figure 2: The phase difference for both ambiguous solutions between the $1^{--}1^{-}P$ and $1^{+-}0^{-}S$ waves.

3. MASS DEPENDENT ANALYSIS

In order to better understand the nature of the $1^{+-}0^{+}S$ and the $1^{--}1^{+}P$ observed structures, a mass dependent analysis of the PWA results was performed. The input quantities included the $1^{+-}0^{+}S$ and $1^{--}1^{+}P$ wave intensities, and their relative phase for each mass bin. Relativistic Breit-Wigner forms were used to parameterize the amplitudes for the two waves.

Many mass dependent fits were performed for different hypotheses and for different relative phase motions. The result for the best fit finds both waves resonating with the phase described by Figure 3c. The mass and width of the $1^{+-}0^{+}S$ state are $mass = 1542 \pm 13$ MeV/c^2 and $\Gamma = 285 \pm 30$ MeV/c^2. The mass and width of the $1^{--}1^{+}P$ state are $mass = 1664 \pm 24$ MeV/c^2 and $\Gamma = 219 \pm 63$ MeV/c^2. Figure 3 displays the results of the mass dependent analysis: $3a$, $3b$, and $3c$ show results of this fit overlaid on the partial wave intensities and relative phase. Figure $3d$ shows the absolute Breit-Wigner phases for 1^{--} and 1^{+-} and the relative constant production phase.

Assuming that the observed $1^{--}1^{+}P$ state is identified with the $\omega(1600)$ and that the $1^{+-}0^{+}S$ object is a single resonance, then the $1^{+-}0^{+}S$ wave is also resonating with a mass of 1542 ± 13 MeV/c^2 and a width of 285 ± 30 MeV/c^2; this state would be interpreted as a new $h_1(1540)$ state.

Possible interpretations for an $h_1(1540)$ include an h_1 radial excitation, an h_1 hybrid, or a radial-hybrid mixture. In the Godfrey-Isgur potential model[4], a mass of 1780 MeV/c^2 was predicted for the $2\,^3P_0$ h_1 radial excitation. However, their model also predicts a high mass for the $h_1(1160)$ and a high mass for the $h_1(1380)$ (1220 MeV/c^2 and 1470 MeV/c^2, respectively), therefore one might expect the radial state to actually lie 100-200 MeV/^{2} below the Godfrey-Isgur prediction. More recently, a calculation by T. Barnes[5] using a $^3P_0$ model suggests that a 1700 MeV/c^2 h_1 radial excitation should decay almost equally to $1^{+-}S$ and $1^{+-}D$ partial waves[2] which are not what we observe. Alternatively, since the flux-tube model predicts a $J^{PC} = 1^{+-}$ hybrid near 1900-2000 MeV/c^2[6] and exotic states have been reported at masses lower than the flux-tube model expectations[7,8], the $h_1(1540)$ can be a candidate for a hybrid or radial-hybrid mixed state.

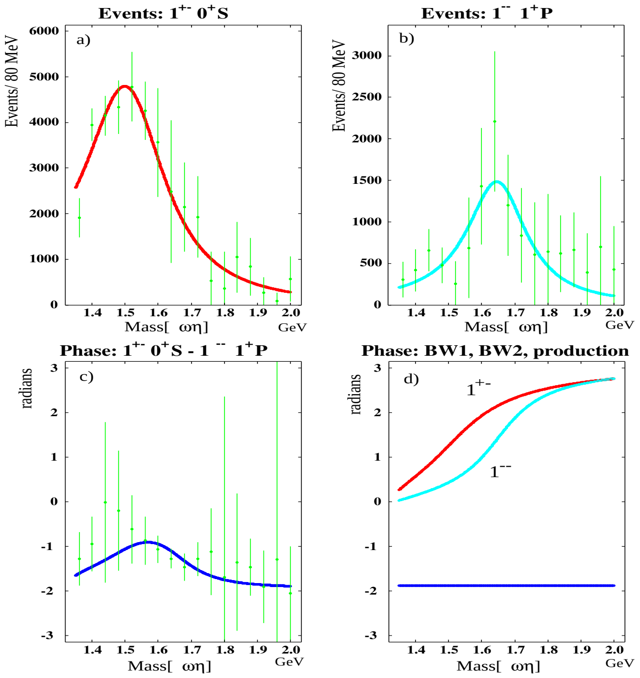

Figure 3: Mass dependent analyses of the $1^{+-}0^{+}S$ and $1^{--}1^{+}P$ waves show that the 2 waves are well described by two interfering Breit-Wigner resonances. The 1^{--} state of $mass = 1664 \pm 24$ MeV/c^2 and $\Gamma = 219 \pm 63$ MeV/c^2 is in good agreement with the PDG values for the $\omega(1600)$ of $mass = 1649 \pm 24$ MeV/c^2 and $\Gamma = 220 \pm 35$ MeV/c^2. This is the first observation of $\omega(1600) \rightarrow \omega\eta$. A new 1^{+-} state with $mass = 1542 \pm 13$ MeV/c^2 and $\Gamma = 285 \pm 30$ MeV/c^2 is observed.

REFERENCES

1. P. Eugenio, *Meson Spectroscopy in $\pi^- p$ Interactions at 18 GeV/c –Recent Results from Brookhaven E852*, these proceedings.
2. S.U. Chung and T.L. Trueman, *Phys. Rev.* **D11** 633, (1975).
3. Particle Data Group, *Phys. Rev.* **D54** 1, (1996).
4. S. Godfrey and N. Isgur, *Phys. Rev.* **D32** 189, (1985).
5. Barnes, Close, Page, and Swanson, *Phys. Rev.* **D55** 4157, (1997).
6. F. Close and P. Page, *Nucl. Phys.* **B443** 233, (1995).
7. D. R. Thompson *et. al.*, *Phys. Rev. Lett.* **79**, 1630, (1997).
8. G. S. Adams *et. al.*, *Phys. Rev. Lett.* **81**, 5760,(1998).

[2] The calculation is mass dependent, and one expects the S to D wave ratio to increase for a lower mass h_1 state due to angular momentum barrier effects.