A study of the $\eta\pi^+\pi^-$ channel produced in central pp interactions at 450 GeV/c

WA102 Collaboration


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The reaction $pp \rightarrow p(p(\eta\pi^+\pi^-))p$, has been studied at 450 GeV/c. There is clear evidence for an $a_2(1320)$ decay mode of the $\eta_2(1645)$ and $\eta_2(1870)$. In addition, there is evidence for an $a_0(980)$ decay mode of both resonances and an $f_2(1270)\eta$ decay mode of the $\eta_2(1870)$. No evidence is found for a $J^{PC}=2^{++}$ $a_2(1320)$ wave.

In an analysis of the $\pi^+\pi^-\pi^+\pi^-$ final state the WA102 collaboration observed three peaks in the mass spectrum [1]. A spin analysis showed that the peak at 1.28 GeV was due to the $f_1(1285)$, the peak at 1.51 GeV was due to the $f_2(1525)$, and the peak at 1.75 GeV was due to the $f_3(1700)$.
at 1.45 GeV could be interpreted as being due to interference between the $f_0(1370)$ and $f_0(1500)$ and the peak at 1.9 GeV, called the $f_2(1950)$, was found to have $I^P J^{PC} = 0^+ 2^{++}$ and decay to $f_2(1270)\pi\pi$ and $a_0(1320)\pi\pi$ [1]. However, it was not possible to determine whether the $f_2(1950)$ was one resonance with two decay modes, or two resonances, or if one of the decay modes was spurious.

One of the major problems of studying the $\pi^+\pi^-\pi^+\pi^-$ final state is the number of possible isobar decay modes that are present. Therefore in this paper, in order to study the $a_0(1320)\pi\pi$ final state, an analysis is presented of the $\eta\pi^+\pi^-\pi^-$ channel. In addition, the spin analysis of the $\pi^+\pi^-\pi^+\pi^-$ channel showed evidence in the $J^{PC} = 2^{++} a_0(1320)\pi$ wave for the $\eta_8(1645)$ and $\eta_8(1870)$. There has been previous evidence [2] that the $\eta_8(1645)$ and $\eta_8(1870)$ may decay to $a_0(980)\pi\pi$ and $f_2(1270)\eta$. These two decay modes will be searched for in the present analysis.

The data come from the WA102 experiment which has been performed using the CERN Omega Spectrometer, the layout of which is described in Ref. [3]. The selection of the reaction

$$pp \rightarrow p_f(\eta\pi^+\pi^-)p_s \tag{1}$$

where the subscripts $f$ and $s$ indicate the fastest and slowest particles in the laboratory respectively, has been described in Ref. [4]. The $\eta$ has been observed decaying to $\gamma\gamma$ and $\pi^+\pi^-\pi^0$. Fig. 1a and 1b show the $\eta\pi^+\pi^-$ mass spectra for the decays $\eta \rightarrow \gamma\gamma$ and $\eta \rightarrow \pi^+\pi^-\pi^0$ respectively. The mass spectra are dominated by the $\eta'$ and $f_2(1285)$.

In this current paper a spin-parity analysis of the $\eta\pi^+\pi^-$ channel is presented for the mass interval 1.0 to 2.0 GeV using an isobar model [5]. Assuming that only angular momenta up to 2 contribute, the intermediate states considered are $a_0(980)\pi\pi$, $\sigma\eta$, $f_0(1500)\pi\pi$, $a_0(1320)\pi\pi$, and $f_2(1270)\eta$. $\sigma$ stands for the low mass $\pi\pi$ S-wave amplitude squared [6]. The amplitudes have been calculated in the spin-orbit (LS) scheme using spherical harmonics. In order to perform a spin parity analysis the Log Likelihood function, $\mathcal{L} = \sum \log P_i$, is defined by combining the probabilities of all events in 40 MeV $\eta\pi^+\pi^-$ mass bins from 1.0 to 2.0 GeV. The incoherent sum of various event fractions $a_i$ is calculated so as to include more than one wave in the fit, using the form:

$$\mathcal{L} = \sum \log \left( \sum a_j P_j(i) + 1 - \sum_j a_j \right) \tag{2}$$
where the term \((1 - \sum a_i)\) represents the phase space background. This background term is used to account for the background below the \(\eta\) (which is 10% for the \(\gamma \gamma\) decay mode and 15% for the \(\pi^+\pi^-\pi^0\) decay mode), \(\eta \pi^+\pi^-\) three body decays and decay modes not parameterised in the fit. The negative Log Likelihood function \((-\mathcal{L})\) is then minimised using MINUIT [7]. Different combinations of waves and isobars have been tried and insignificant contributions have been removed from the final fit.

The spin analysis has been performed independently for the two \(\eta\) decay modes. As was shown in the previous analysis [4], for both decay modes and for \(M(\eta \pi^+\pi^-) \leq 1.5\) GeV the only wave required in the fit is the \(J^{PC} = 1^{++} a_0(980)\) wave with spin projection \(|J_z| = 1\). No \(J^{PC} = 0^{++} a_0(980)\) or any \(\sigma \gamma \eta\) waves are required in the fit. Fig. 2a and Fig. 3a show the \(J^{PC} = 1^{++} a_0(980)\) wave where the \(f_0(1285)\) and a shoulder at 1.4 GeV can be seen. Superimposed on the waves is the result of the fit used in Ref. [4] which uses a K matrix formalism including poles to describe the interference between the \(f_0(1285)\) and the \(f_0(1420)\). As can be seen from Fig. 2a and Fig. 3a the parameterisation describes well the \(J^{PC} = 1^{++} a_0(980)\) wave.

For \(M(\eta \pi^+\pi^-) \geq 1.5\) GeV only waves with \(J^{PC} = 2^{++}\) and \(|J_z| = 1\) are required in the fit. In contrast to what was found in the analysis of the \(\pi^+\pi^-\pi^0\) final state [1] there is no evidence for any \(J^{PC} = 2^{++} a_0(1320)\) wave. The largest change in Log Likelihood comes from the addition of the \(J^{PC} = 2^{++} a_0(1320)\) wave with \(|J_z| = 1\) which yields a Likelihood difference \(\Delta \mathcal{L} = 562\) and 203 for the \(\eta \to \gamma \gamma\) and \(\eta \to \pi^+\pi^-\pi^0\) decays respectively and are shown in Fig. 2b and Fig. 3b.

As was observed in the case of the \(\pi^+\pi^-\pi^0\) channel [1], the \(J^{PC} = 2^{++} a_0(1320)\) wave is consistent with being due to two resonances, the \(\eta(1645)\) and the \(\eta(1870)\). Superimposed on Fig. 2b and Fig. 3b is the result of a fit using a single channel K matrix formalism [9] with two resonances to describe the \(\eta(1645)\) and \(\eta(1870)\). The masses and widths determined for each resonance and each \(\eta\) decay mode are given in Table 1. The parameters found are consistent for the two decay modes and with the PDG [8] values for these resonances. An alternative fit has been performed using two interfering Breit-Wigners. The parameters presented include not only the statistical error but also the systematic error, added in quadrature, representing the difference in the two fits.

The addition of the \(J^{PC} = 2^{++} a_0(980)\) wave with \(|J_z| = 1\) yields a Likelihood difference \(\Delta \mathcal{L} = 66\) and 23 for the two \(\eta\) decay modes respectively and the waves are shown in Fig. 2c and Fig. 3c. Superimposed is the result of a fit using the parameters for

<table>
<thead>
<tr>
<th>Resonance</th>
<th>Final state</th>
<th>Mass (MeV)</th>
<th>Width (MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\eta(1645))</td>
<td>(\eta \pi \pi)</td>
<td>(1605 \pm 12)</td>
<td>(188 \pm 22)</td>
</tr>
<tr>
<td>(\eta(1645))</td>
<td>(\eta \to \gamma \gamma)</td>
<td>(1619 \pm 11)</td>
<td>(179 \pm 28)</td>
</tr>
<tr>
<td>(\eta(1870))</td>
<td>(\eta \pi \pi)</td>
<td>(1841 \pm 18)</td>
<td>(249 \pm 30)</td>
</tr>
<tr>
<td>(\eta(1870))</td>
<td>(\eta \to \gamma \gamma)</td>
<td>(1831 \pm 16)</td>
<td>(219 \pm 33)</td>
</tr>
</tbody>
</table>
the $\eta_1(1645)$ and the $\eta_2(1870)$ determined from the fit to the $a_2(1320)\pi$ final state. A good description of the data is found. The branching ratio of the $\eta_1(1645)$ and $\eta_2(1870)$ to $a_2(1320)\pi/\alpha_0(980)\pi$ in the $\eta\pi\pi$ final state can be determined. Neglecting unseen decay modes the branching ratio of $\eta_1(1645)$ to $a_2(1320)\pi/\alpha_0(980)\pi = 2.3 \pm 0.4$ and $2.1 \pm 0.5$ for the decays $\eta \rightarrow \gamma\gamma$ and $\eta \rightarrow \pi^+\pi^-\pi^0$ respectively. The branching ratio of $\eta_2(1870)$ to $a_2(1320)\pi/\alpha_0(980)\pi = 5.0 \pm 1.6$ and $6.0 \pm 1.9$ respectively.

Correcting for the unseen $a_2(1320)$ decay modes using the PDG [8] branching ratio and using the branching ratio for the $\alpha_0(980)$ to $\eta\pi$ determined by this experiment [4] of $0.86 \pm 0.10$ and taking the average of the two $\eta$ decay modes the branching ratio to $a_2(1320)\pi/\alpha_0(980)\pi$ for the $\eta_1(1645)$ is $13.0 \pm 2.7$ and for the $\eta_2(1870)$ is $32.6 \pm 12.6$.

The addition of the $J^{PC} = 2^+ f_2(1270)\eta$ wave with $|J_f| = 1$ yields a Likelihood difference $\Delta \mathcal{L} = 42$ and 12 and the waves are shown in Fig. 2d and Fig. 3d. The $f_2(1270)\eta$ wave shows little evidence for the $\eta_2(1645)$. Superimposed is the result of a fit using the parameters for the $\eta_1(1870)$ determined from the fit to the $a_2(1320)\pi$ final state. A satisfactory description of the data is found. Correcting for the unseen $a_2(1320)$ and $f_2(1270)$ decay modes the branching ratio of the $\eta_1(1870)$ to $a_2(1320)\pi/\alpha_0(980)\pi$ has been determined to be $19.2 \pm 7.2$ and $26.7 \pm 16.4$ for the two $\eta$ decay modes. The addition of the $J^{PC} = 2^{-+} f_0(980)\eta$ or $J^{PC} = 2^{-+} \sigma \eta$ waves produces no significant change in the Likelihood and hence they have been excluded from the fit. The resulting background term is found to be smooth and structureless and corresponds to $\approx 40\%$ of the channel.

In previous analyses it has been observed that when the centrally produced system has been analysed as a function of the parameter $dP_T$, which is the difference in the transverse momentum vectors of the two exchange particles [3,10], all the undisputed $q\bar{q}$ states (i.e. $\eta$, $\eta'$, $f_0(1285)$ etc.) are suppressed as $dP_T$ goes to zero, whereas the glueball candidates $f_0(1500)$, $f_0(1710)$ and $f_0(1950)$ are prominent [11]. In order to calculate the contribution of each resonance as a function of $dP_T$, the waves have been fitted in three $dP_T$ intervals with the parameters of the resonances fixed to those obtained from the fits to the total data. Table 2 gives the percentage of each

<table>
<thead>
<tr>
<th>$dP_T \leq 0.2$ GeV</th>
<th>$0.2 \leq dP_T \leq 0.5$ GeV</th>
<th>$dP_T \geq 0.5$ GeV</th>
<th>$R = \frac{dP_T \leq 0.2 \text{ GeV}}{dP_T \geq 0.5 \text{ GeV}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\eta_1(1645)$</td>
<td>$8.9 \pm 1.1$</td>
<td>$32.2 \pm 3.0$</td>
<td>$58.9 \pm 5.2$</td>
</tr>
<tr>
<td>$\eta_2(1870)$</td>
<td>$8.2 \pm 1.0$</td>
<td>$28.6 \pm 2.8$</td>
<td>$63.2 \pm 5.6$</td>
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</tbody>
</table>
Table 3

<table>
<thead>
<tr>
<th></th>
<th>$\alpha$</th>
<th>$b_1$ (GeV$^{-1}$)</th>
<th>$\beta$</th>
<th>$b_2$ (GeV$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\eta(1645)$</td>
<td>0.4 ± 0.1</td>
<td>6.4 ± 2.0</td>
<td>2.6 ± 0.9</td>
<td>7.3 ± 1.3</td>
</tr>
<tr>
<td>$\eta(1870)$</td>
<td>0.3 ± 0.1</td>
<td>5.9 ± 3.5</td>
<td>4.3 ± 1.5</td>
<td>8.3 ± 2.0</td>
</tr>
</tbody>
</table>

There is no evidence for any $q\bar{q}$ wave, in particular no evidence for the decay $\eta(1870)$ into the $q\bar{q}$ final state. In addition, there is evidence for $\eta(1320)$ decay mode of both resonances and possibly $f_2(1270)\eta$ decay mode of the $\eta(1870)$. There is no evidence for any $J^{PC} = 2^{--}$ final state. In addition, there is evidence for $\eta(1870)$ to decay into $a_2(1320)\pi$ wave, in particular no evidence for the decay $f_2(1270)$ to $a_2(1320)\pi$.

Acknowledgements

This work is supported, in part, by grants from the British Particle Physics and Astronomy Research Council, the British Royal Society, the Ministry of Education, Science, Sports and Culture of Japan (grants no. 07044098 and 1004100), the French Programme International de Cooperation Scientifique (grant no. 576) and the Russian Foundation for Basic Research (grants 96-15-96633 and 98-02-22032).

References