Further Study of 1^{-+} Exotic Meson in the Reaction $\pi^- p \to \eta\pi^- p$ at 18 GeV/c

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ABSTRACT

Details of the analysis of the $\eta\pi^-$ system studied[1] in the reaction $\pi^- p \to \eta\pi^- p$ at 18 GeV/c are given. The amplitude analysis indicates the presence of interference between the $a_2(1320)$ and a $J^{PC} = 1^{-+}$ wave between 1.2 and 1.6 GeV/c^2. The phase difference between these waves shows phase motion not attributable solely to the $a_2(1320)$. The data can be fitted by interference between the $a_2(1320)$ and an exotic 1^{-+} resonance with M = (1370 ± 16 $^{+50}_{-30}$) MeV/c^2 and Γ = (385 ± 40 $^{+65}_{-105}$) MeV/c^2.

1. Introduction

The $\eta\pi$ system is particularly interesting in searching for exotic (or non-$q\overline{q}$) mesons because the system has spin (J), parity (P), and charge-conjugation (C) in the sequence $J^{PC} = 0^{++}, 1^{-+}, 2^{++}, 3^{-+}...$ for $\ell = 0, 1, 2, 3, ...$. (Here ℓ is the orbital angular momentum of the $\eta\pi$ system.) A $q\overline{q}$ meson with orbital angular momentum L and total spin S must have $P = (-1)^{L+1}$ and the neutral member of its isospin multiplet must have $C = (-1)^{L+S}$. A resonance with a quantum number in the sequence $J^{PC} = 0^{--}, 0^{+-}, 1^{-+}, 2^{+-}, 3^{-+} \cdots$ does not satisfy these conditions and must be exotic. Having isospin I=1, such a resonance could not be a glueball $(2g, 3g, \ldots)$, but it could be a hybrid $(q\overline{q}g)$ or a multiquark $(q\overline{q}q\overline{q})$ state.

Several experiments,[2–5] prior to the publication of the E852 results,[1] had studied the $\eta\pi$ final state, and observed an enhancement in the P wave around 1.4 GeV/c^2 . However, they reached conflicting conclusions.

The first credible claim for a 1^{-+} exotic resonance was made by our experiment at BNL.[1] In this paper we present some details of the analysis. We note that since the publication of our letter, an independent confirmation of our results has come from a new measurement by the Crystal Barrel collaboration.[6]

2. Data and PWA

Our data sample was collected in the first data run of E852 at the Alternating Gradient Synchrotron (AGS) at Brookhaven National Laboratory (BNL) with the Multi-Particle Spectrometer (MPS) augmented by additional detectors. The details of the E852 apparatus are given elsewhere.[7]

Of the 47 million triggers, 47,235 events were reconstructed[1] which were consistent with the reaction

$$\pi^- p \rightarrow \eta\pi^- p \tag{1}$$

at 18 GeV/c, with the decay mode $\eta \rightarrow \gamma\gamma$.

The background is approximately 7% at 1.2 GeV/c^2, and only 1% at 1.3 GeV/c^2.

A partial-wave analysis (PWA)[8–10] based on the extended maximum likelihood method has been used to study the spin-parity structure of the $\eta\pi^-$ system.

The partial waves are parameterized in terms of the quantum numbers J^{PC} as well as m, the absolute value of the angular momentum projection, and the reflectivity ϵ.[11] In our naming convention, a letter indicates the angular momentum of the partial wave in standard spectroscopic notation, while a subscript of 0 means $m = 0$, $\epsilon = -1$, and a subscript of $+(-)$ means $m = 1$, $\epsilon = +1(-1)$. Thus, S_0 denotes the partial wave having $J^{PC}m^\epsilon = 0^{++}0^-$, while P_- signifies $1^{-+}1^-$, D_+ means $2^{++}1^+$, and so on.

The results of the PWA fit for the D_+ and P_+ intensities and the phase difference between these amplitudes, $\Delta\Phi$, are shown in Fig.1.

3. Leakage

The Monte-Carlo study shows that the intensity and phase motion of the P_+ wave do not have the characteristics of a wave which is artificially generated from a pure D_+ wave due to possible incomplete knowledge of the resolution or detection inefficiency. This does not preclude the possibility of some leakage of D_+ wave to P_+ wave being present in the data and distorting the results of the mass dependent fit[1] (MDF). In this section, we describe a test which has been carried out to study the sensitivity of our MDF results to possible residual leakage being present in the data.

The fit has been carried out is a mass dependent partial wave analysis (MDPWA). In such a fit, the PWA is carried out so that all $\eta\pi^-$ mass bins are fit simultaneously and are tied together with a mass-dependent function for each partial wave. That is, the extended maximum likelihood function is generalized to include mass dependence:

$$\ln\mathcal{L} \propto \sum_i^n \ln I(\Omega_i, w_i) - \int \mathrm{d}\Omega \mathrm{d}w \; \eta(\Omega, w)\, I(\Omega, w). \tag{2}$$

The free parameters in the fit include, in addition to the amplitudes of the partial waves, the Breit-Wigner masses, widths, and intensities as well as mass-independent production amplitude phases.

The results of the MDPWA fit are shown as the smooth curves in Fig.1. Also shown as the points with error bars are the results of the standart PWA.[1] It is clear that the two analyses give consistent results.

4. Conclusion

The results of the MDPWA fit are given in Table 1, where they are compared with those of the combined PWA and mass dependent fit (PWA+MDF). The results are quite compatible when one takes into account the systematic errors. The biggest difference is in the fitted width of the P_+ state which is larger for the MDPWA.

Table 1. Comparison of the results of the PWA combined with a separate mass dependent fit (MDF) with those of the MDPWA with leakage.

Meson		Mass (MeV/c^2)	Width (MeV/c^2)
$a_2(1320)$	E852 (PWA+MDF)	1317 ± 1 ± 2	127 ± 2 ± 2
	E852 (MDPWA)	1313 ± 1	119 ± 2
$\pi_1(1400)$	E852 (PWA+MDF)	1370 ± 16 $^{+50}_{-30}$	385 ± 40 $^{+65}_{-105}$
	E852 (MDPWA)	1369 ± 14	517 ± 40

Table 2. Comparison of the results of E852 and the Crystal Barrel for the parameters of the $J^{PC} = 1^{-+}$ resonance.

$\pi_1(1400)$	Mass (MeV/c^2)	Width (MeV/c^2)
E852	1370 ± 16 $^{+50}_{-30}$	385 ± 40 $^{+65}_{-105}$
Crystal Barrel	1400 ± 20 ± 20	310 ± 50 $^{+50}_{-30}$

Our fitted parameters for the $J^{PC} = 1^{-+}$ resonance are compared in Table 2 with values recently reported by the Crystal Barrel experiment.[6] That experiment reports that a $J^{PC} = 1^{-+}$ resonance in the $\eta\pi$ channel is required to fit their data in the annihilation channel $\overline{p}n \to \pi^-\pi^0\eta$. Their fitted parameters are very consistent with those determined from our mass-dependent analysis.

So, since the resonance state has $J^{PC} = 1^{-+}$, it is manifestly exotic.

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Fig. 1. The fit results of the MDPWA (curves) and the mass independent PWA results (crosses) for the $\eta\pi^-$ system: a) P_+ , b) D_+ intensities and c) their relative phase $\Delta\phi(P_+ - D_+)$. Fig.1a also shows the contributions of the 1^{-+} signal intensity (1), the sum (2) of the leakage and the (signal - leakage) interference term and the complete 1^{-+} wave (3).