Exotic $\eta\pi$ State in $\bar{\mathrm{p}}\mathrm{n} \to \pi^-\pi^0\eta$

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Introduction

The $\eta\pi$ system is attractive for the exotics search since its P-wave carries the non-$q\bar{q}$ quantum numbers $J^{PC} = 1^{-+}(G = -)$. Resonant behavior around 1400 MeV/c^2 was reported by GAMS [1], VES [2], and KEK [3] for the $\eta\pi$ P-wave produced in pion-induced reactions on nucleons. While the resonance parameters extracted from these experiments are mutually inconsistent, recent work from BNL [4] reports good agreement with VES. On the other hand, the additional $\eta'\pi$ data of VES indicate an extension of resonant activity to higher mass [2]. Because of its unequivocally exotic - presumably hybrid or multiquark [5] - structure, it is very important to establish the 1^{-+} resonance by an alternative experimental approach.

The Crystal Barrel Collaboration has studied the $\eta\pi$ P-wave in two annihilation reactions which occur from different initial states and have a different selectivity due to conservation rules:

$$
\begin{array}{lrcl}
\text{(a)} & \bar{\mathrm{p}}\mathrm{n} & \to & \pi^-\pi^0\eta \\
 & {}^3\mathrm{S}_1,\ {}^1\mathrm{P}_1 & \to & \rho^-\eta,\ \mathrm{a}_2\pi,\ (\eta\pi)_{\mathrm{P}}\pi \text{ and } \mathrm{a}_0\pi \text{ from } {}^1\mathrm{P}_1 \text{ only} \\
\text{(b)} & \bar{\mathrm{p}}\mathrm{p} & \to & \pi^0\pi^0\eta \\
 & {}^1\mathrm{S}_0,\ {}^3\mathrm{P}_1,\ {}^3\mathrm{P}_2 & \to & \mathrm{f}_0\eta,\ \mathrm{f}_2\eta,\ \mathrm{a}_0\pi,\ \mathrm{a}_2\pi,\ (\eta\pi)_{\mathrm{P}}\pi
\end{array}
$$

In our previous investigation [6] of the annihilation (b), a rather small but significant $(\eta\pi)_{\mathrm{P}}\pi$ contribution was found. However, fits to the data were not sensitive to variations of the width in the range $\Gamma \gtrsim 400\mathrm{MeV/c^2}$. Because of the complexity of the f_0 and the other contributions listed above, the Dalitz plot (DP) of reaction (b) is rich in structure [6]. In contrast, the selectivity of reaction (a) results in a simple structure of the DP, ideally suited for an interferometric study of the $\eta\pi$ P-wave.

Results and Partial Wave Analysis

The annihilation (a) was studied with 200 MeV/c antiprotons from LEAR stopped in a liquid deuterium target. From a total of 8.2 million 1-prong events, a sample of 52576 events of the type $\bar{p}d \to \pi^-\pi^0(\gamma\gamma)\eta(\gamma\gamma)p$ with a spectator proton momentum < 100 MeV/c was kinematically selected. Background from misidentified events of other origin contributes about 0.5%. The experimental intensity distribution (Fig. 1) is characterized by a simple pattern with a dominant diagonal $\rho^-(770)$ band and two weaker orthogonal bands in the region of the $a_2(1320)$. The latter show large modulations typical of interference effects. If the smooth variation of the experimental acceptance is taken into account, the distribution is symmetric with respect to π^0/π^- exchange, which is consistent with the assumed spectator role of the proton.

The partial wave analysis of this intensity distribution assumes intermediate two-body states of $\pi^-\pi^0$ resonances with a recoiling η or $\eta\pi$ with a recoiling π. The transition amplitudes [6], [7] contain relativistic Breit-Wigner terms that parameterize the resonances. A good fit ($\chi^2/N_{dof} = 506/391 = 1.29$) is obtained with the simple model space of intermediate states listed in Table 1. The resonant $\eta\pi$ P-wave contributes a significant fraction, summing up to 11% plus the interferences. In addition to the accumulation of intensity in the central region of the DP, its most significant contributions arise from interference with the ρ^- and a_2 resonances, as becomes evident by comparing Figs. 2 and 3. With a model space that does not include the $\eta\pi$ P-wave but all other allowed known resonances or candidates (a_0, excited ρ^- and a_2) no satisfactory fits are obtained and the χ^2 distribution gives evidence for missing interference structures (Fig. 4), in contrast to the fit model of Table 1 [8].

TABLE 1. Fitted annihilation amplitudes. The relative rates, obtained by integrating over phase space, do not add up to 100% since they are normalized to the total intensity which includes all mutual interferences for each of the two incoherent initial states. For the $a_2\pi$ and $(\eta\pi)_P\pi$ intermediate states the given rates refer to the coherent sum of both charge combinations. (The absolute branching for $\bar{p}n \to \pi^-\pi^0\eta$ is $(1.41 \pm 0.15)\%$ [8] .)

	Amplitude	Rate from $^3S_1$	Rate from $^1P_1$
$\bar{p}n$	$\to \rho^-(770)\eta$	30.0 ± 3.5	$10.3 \pm 3.0(L=0), 17.3 \pm 1.2(L=2)$
	$\to a_2(1320)\pi$	11.1 ± 1.0	3.8 ± 0.8
	$\to (\eta\pi)_P\pi$	7.9 ± 1.0	$2.8 \pm 1.3(L=0), 0.5 \pm 0.5(L=2)$

Resonance Characteristics

The interference of the $\eta\pi$ P-wave with both the ρ^- and the a_2 resonances pins down the resonance characteristics. The relative phase of the latter two resonances is well determined by their crossing in the DP. It is close to 0° for the $^3S_1$ initial state. Both probe the $\eta\pi$ phase motion in different regions. Constructive and destructive interference on opposite sides of the ρ^- band center is visible in Fig 2 (cf. Fig 3). Moving along a parallel just below the

ρ^- band, one observes the rise and the fall of the constructive term, which reflects the almost complete phase rotation of the $\eta\pi$ resonance. The additional interference minima and maxima arising from the a_2 overlap complement the fingerprint of the exotic resonance (cf. Figs. 1-4). The interference with the ρ^- resonance constitutes the essential difference from studies of pion-induced reactions which are confined to the interference with a dominant a_2 ([1]- [4]).

The fit is rather sensitive to the resonance width and in particular a nonresonant $\eta\pi$ P-wave, simulated by a very large Breit-Wigner resonance width, is excluded [8]. As an alternative model of the $\eta\pi$ P-wave, an effective range amplitude is found to yield convergent or divergent fits in the range of scattering parameters that characterize resonant or nonresonant behavior, respectively.

To investigate a possible threshold effect from the $f_1\pi(1420\mathrm{MeV/c^2})$ system, the Flatté form of the resonance amplitude was employed, which introduces the width $\Gamma_{f_1\pi}$ as additional parameter ([7]). It is possible to fit the data with several choices of $\Gamma_{\eta\pi}$, in particular with much larger values than required by the simple Breit-Wigner fit, in which case the cusp induced by the opening of the threshold channel accounts for the narrower experimental structure. However, this demands peculiar initial state intensities in the fit, e.g. in the case of $\Gamma_{\eta\pi} = 1\mathrm{GeV/c^2}$, $\mathrm{I}(^1\mathrm{P}_1)/\mathrm{I}(^3\mathrm{S}_1) = $ 2:1 and 1:5 for ρ^- and a_2, respectively, and an appreciable $f_1\pi$ rate that would be detectable by experiment.

To summarize, we have extracted the following Breit-Wigner resonance parameters of the exotic $\eta\pi$ P-wave:
$\mathrm{m} = (1400 \pm 20_{\mathrm{stat}} \pm 20_{\mathrm{syst}})\mathrm{MeV/c^2}$, $\Gamma = (310 \pm 50_{\mathrm{stat}} + 50/-30_{\mathrm{syst}})\mathrm{MeV/c^2}$. Additional resonance structure beyond $1.7\,\mathrm{GeV/c^2}$ is not excluded, because of the present phase space limitation, but may be required to reconcile the various results for pion-induced reactions ([1]- [4]). The present observation of resonant behavior was made possible by the large relative rate of the $\eta\pi$ P-wave, which is comparable to the a_2 rate and which exceeds by far the rate in the annihilation (b), and by the superposition with two other resonances.

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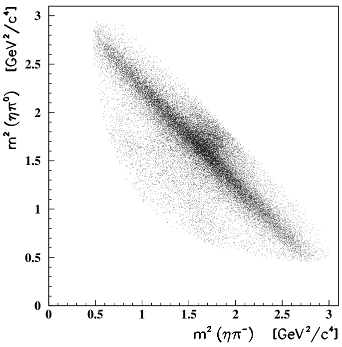

FIGURE 1. Dalitz plot (not acceptance corrected, not symmetrized) of the final sample of 52576 $\pi^-\pi^0\eta$ events from the annihilation reaction $\bar{\mathrm{p}}\mathrm{d} \rightarrow \pi^-\pi^0\eta\mathrm{p}_{\mathrm{spectator}}$ with $\mathrm{P}(\mathrm{p}_{\mathrm{spectator}}) < 100\mathrm{MeV/c}$.

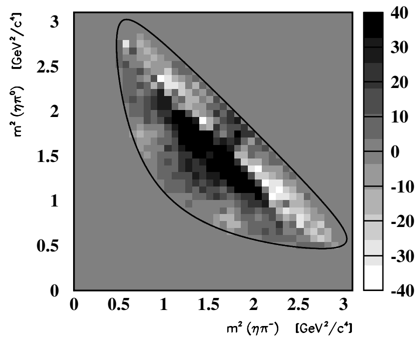

FIGURE 2. Difference between the acceptance corrected experimental intensity and the ρ^- and a_2 contributions of the fit (Table 1). This intensity difference is accounted for by the fitted $(\eta\pi)_{\mathrm{P}}$ contributions and their interferences with ρ^- and a_2. The sum of these is shown in [8], the dominant components are shown below.

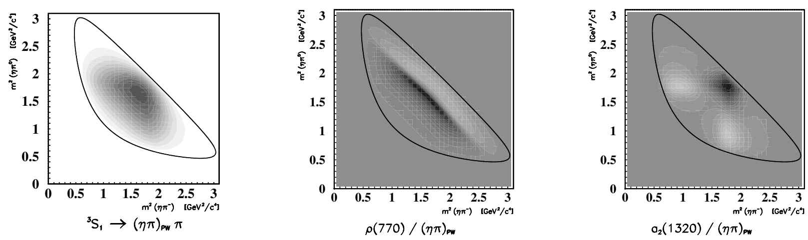

FIGURE 3. Intensity distribution of the fitted $^3\mathrm{S}_1 \rightarrow (\eta\pi)_{\mathrm{P}}\pi$ amplitude and of its interferences with the $^3\mathrm{S}_1 \rightarrow \rho^-\eta$ and with the $^3\mathrm{S}_1 \rightarrow \mathrm{a}_2\pi$ amplitudes.

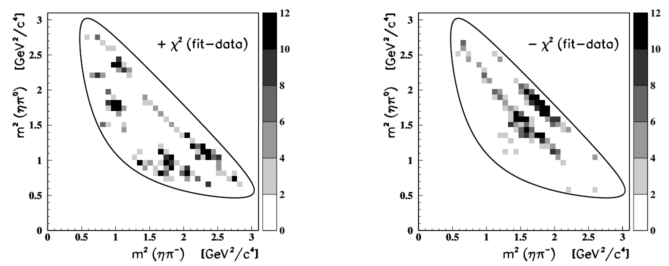

FIGURE 4. Deviation of the experimental intensity from a fit ($\chi^2/\mathrm{N}_{\mathrm{dof}} = 3.1$) that includes $\rho^-(770), \mathrm{a}_2(1320), \mathrm{a}_0(980)$ and $\mathrm{a}_0(1450)$, but no $(\eta\pi)_{\mathrm{P}}$ contributions. The left panel (fit exceeding the data) gives evidence for destructive interference, the right panel (data exceeding the fit) for constructive interference of the missing $(\eta\pi)_{\mathrm{P}}$ amplitude with the ρ^- and a_2 amplitudes.