EXOTIC MESON PRODUCED IN ANTIPROTON-NEUTRON ANNIHILATION: $\hat{\rho} \rightarrow \eta\pi$

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We report on an exotic resonance, decaying into $\eta\pi$, observed in the $\overline{p}n$ annihilation channel $\eta\pi^-\pi^0$. Antiprotons from LEAR were stopped in a liquid deuterium target. Using the Crystal Barrel Detector, 53×10^3 events of the type $\overline{p}d \rightarrow \eta\pi^-\pi^0 p$ with proton spectator momentum $<$ 100 MeV/c were fully reconstructed.The $\eta\pi$ P-wave, carrying quantum numbers ($J^{PC} = 1^{-+}$) not accessible for a quark-antiquark system, is produced with a large relative rate (11%) in this highly selective annihilation channel. Together with the other two dominant resonances, $\rho(770)$ and $a_2(1320)$, it generates a simple pattern in the Dalitz plot of the intensity distribution. The observed interferences pin down the resonance characteristics of the $\eta\pi$ P-wave. A partial wave analysis yields the Breit-Wigner parameters $m = (1400 \pm 20 \pm 20) MeV/c^2$ and $\Gamma = (310 \pm 50^{+50}_{-30}) MeV/c^2$.

1 Introduction

Mesons with exotic quantum numbers $J^{PC} = 0^{--}, 0^{+-}, 1^{-+}, 2^{+-}, ...$ have necessarily non-$q\overline{q}$ structure due to the generalized Pauli principle. Glueballs and quark-gluon hybrids, but also diquonia ($qq\overline{qq}$) or meson molecules can attain these quantum numbers. Unlike the 0^{++} glueball, mesons with exotic quantum numbers cannot mix with ordinary ($q\overline{q}$) mesons. Thus the identification of a meson with exotic J^{PC} gives unambiguous evidence for other or more constituents than one quark and one antiquark. The present contribution reports on Crystal Barrel's recent observation[1] of an exotic meson with $J^{PC} = 1^{-+}$ decaying into $\eta\pi$.

The $\eta\pi$ system is attractive for the exotics search since its P-wave must carry the non-$q\overline{q}$ quantum numbers $J^{PC} = 1^{-+}$ (G= -). In the experiment it is produced in the annihilation

$$\overline{p}n \rightarrow \pi^-\pi^0\eta$$

The crucial question is whether a resonance exists in the $\eta\pi$ P-wave (Fig.1). Utilizing a different production mechanism, previous work[2–4] on pion-induced reactions on nucleons reported resonant behaviour of the $\eta\pi$ P-wave around 1400 MeV/c^2. While some of these and other experiments seemed to be mutually inconsistent, the recent detailed results from BNL[4] are in agreement with the more qualitative results from VES[3]. Clearly, the first exotic meson with an exotic address deserves various inquiries by alternative experiments before it reaches full respectability.

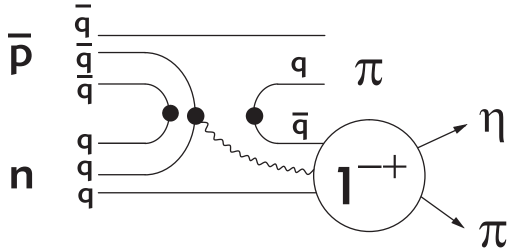

Figure 1: Quarkline diagram of $\overline{p}n$ annihilation into π and the exotic 1^{-+} resonance ("$\hat{\rho}$"), which may be a hybrid (as shown here) or a ($qq\overline{qq}$) state or a meson molecule.

2 Experimental Results and Partial Wave Analysis

Antiprotons with a momentum of 200 MeV/c from the LEAR facility at CERN were stopped in a liquid deuterium target. The Crystal Barrel Detector is equipped for charged particle tracking in a magnetic field of 1.5 T and proton spectroscopy with a highly granular CsI calorimeter, both with close-to-4π geometry[1]. (After closure of LEAR it is presently being rebuilt at ELSA in Bonn.)

From a total of 8.2 million 1-prong events, corresponding to about 10^8 $\overline{p}d$ events, a sample of 52576 events of the type $\overline{p}d \rightarrow \pi^-\pi^0(\gamma\gamma)\eta(\gamma\gamma)p$ with a proton spectator momentum <100 MeV/c was fully reconstructed and kinematically selected. Background from misidentified events of other origin contributes about 0.5%. The momentum cut was chosen to guaranty the spectator role of the proton, i.e. the negligibility of final state interactions with the produced mesons. This was confirmed by the observed independence of our results on variations of this cut and by the symmetry of the intensity distribution with respect to $\pi^0\pi^-$ exchange.

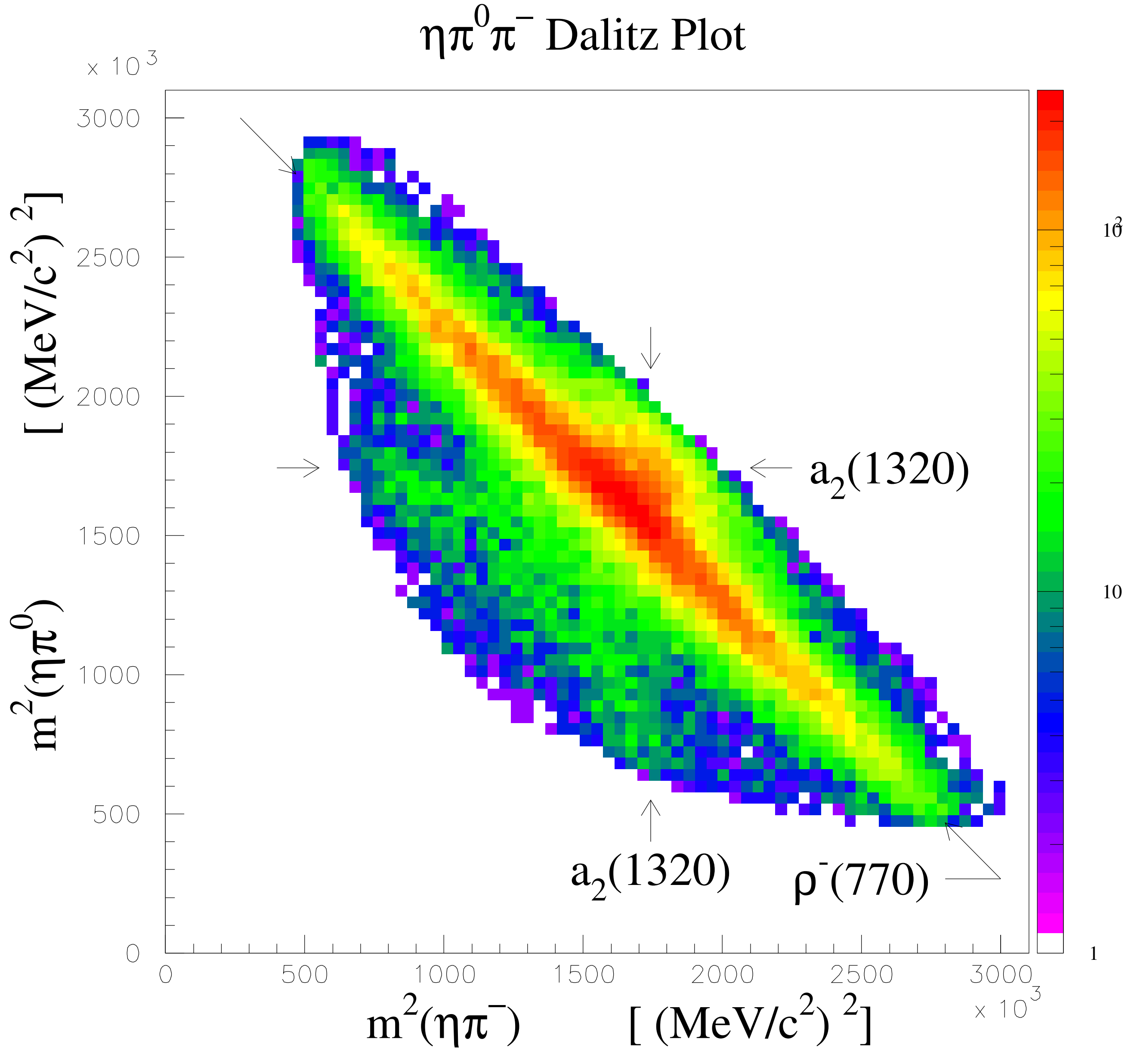

Figure 2: Dalitz plot of the 52576 $\eta\pi^0\pi^-$ events from $\overline{p}d \rightarrow \eta\pi^0\pi^- p_{spectator}$. The experimental intensity distribution was binned and acceptance corrected.

The experimental intensity distribution is displayed as a Dalitz plot in Fig.2. A simple pattern is observed which is dominated by a diagonal $\pi^-(770)$ band and two broad orthogonal bands in the region of the $a_2^{-/0}$ (1320). The latter show large modulations typical of interference effects.

The partial wave analysis of this intensity distribution assumes intermediate states of $\pi^-\pi^0$ resonances with a recoiling η or $\eta\pi$ resonances with recoiling π. Selection rules, based on J, P, G, and I conservation, strongly restrict the model space of intermediate states of the present annihilation channel. All allowed known or candidate resonances with nominal mass inside or close to the phase space boundary were tried in the fits, using relativistic Breit-Wigner resonance parametrizations[1]. A simple model space (A) containing only the $\rho^-(770)\eta, a_2(1320)\pi$ and $(\eta\pi)_P\pi$ intermediate states for each of the two incoherent initial $\overline{p}n$ states,$^3S_1$ and $^1P_1$, is sufficient for a good fit ($\chi^2/N_{dof} = 506/391 = 1.29$). The resonant $\eta\pi$ P-wave contributes a significant fraction, summing up to 11% plus the interferences. Its intensity distribution, including the interferences with the other two dominant resonances, shows a characteristic pattern covering the whole phase space (Fig.3). 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. Its fitted mass of about $1400 MeV/c^2$ and width of about $300 MeV/c^2$ are not significantly affected by various extensions of the model space. 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 interferences (Fig.4). It is noted that conservation laws do not allow a_0 production for the dominant $^3S_1$ initial state. In contrast, the fit model A, which includes the $\eta\pi$ P-wave, yields structureless χ^2 distributions with merely statistical fluctuations[1].

3 Discussion of the Resonant Behaviour of the $\eta\pi$ P-wave

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 0^0 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.3. Moving along a parallel just below the ρ^- band, one observes the rise and the

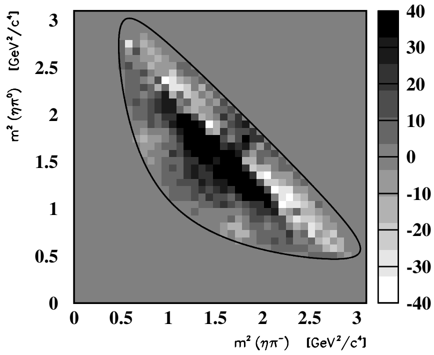

Figure 3: Intensity distribution of the $\eta\pi$ P-wave, as obtained by substracting from the experimental intensity the ρ^- and a_2 contributions of fit model A.

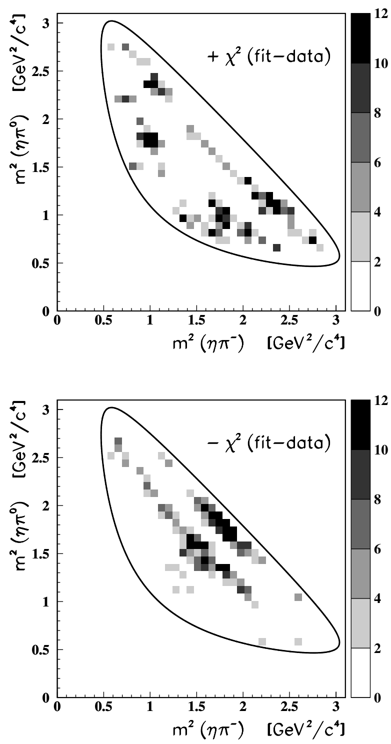

Figure 4: Deviations between the data and a fit that does not include the $\eta\pi$ P-wave but all other allowed resonances. Upper panel: fit exceeds data, lower panel: reverse.

fall of the constructive term, which reflects the almost complete phase rotation of the $\eta\pi$ resonance. Moving along an $m^2(\eta\pi) = (1.7-1.8)GeV^2/c^4$ line, one finds in addition a minimum and a maximum close to the lower and upper phase space boundaries, respectively. These interferences arise from the overlap with the a_2. The interference with the ρ^- resonance constitutes the essential difference from studies of pion-induced reactions[2−4] which are confined to the interference with a dominant a_2.

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 behaviour, respectively. The resonant solution is practically identical to the Breit-Wigner fit amplitude. Its phase motion shows the typical resonance behaviour in an Argand diagram (Fig.5).

The opening of another channel under a broad resonance may create an apparently narrower structure, a so-called cusp. Using an amplitude parametrization that treats this coupled-channels effect in an approximative fashion, we have investigated a possible threshold effect of the $f_1\pi$ system with threshold mass 1420 MeV/c^2. With the rather large $\Gamma_{\eta\pi} = 1GeV/c^2$ a passable fit is obtained (with χ^2 increasing by 42 with respect to fit model A), yielding a resonance mass close to 1400 MeV/c^2. However, the corresponding $f_1\pi$ strength could not be detected, so far. Since additional 1^{-+} resonant structure is found[4] in the mass range 1600 - 1700 MeV/c^2 in $\rho\pi$ and is also indicated[3] in $\eta'\pi$, we investigated the possibility that a broad resonance in that range produces a cusp at 1400 MeV/c^2 in the present channel. However, the corresponding Flatté fit clearly fails to account for the data: χ^2 increases by 120 with respect to fit model A for m = 1700, Γ = 1000 MeV/c^2. However, all observations are consistent with the existence of two 1^{-+} resonances, one at 1400 MeV/c^2, the other at 1600 - 1700 MeV/c^2.

To summarize, we have extracted the following parameters for the $\hat{\rho}$ resonance with $J^{PC} = 1^{-+}$ from a simple Breit Wigner fit (model A) that accounts well for the data:
m = $(1400 \pm 20_{stat} \pm 20_{syst})MeV/c^2$.
$\Gamma = (310 \pm 50_{stat} + 50/-30_{syst})\ MeV/c^2$.
Additional resonance structure above $\approx 1.7GeV/c^2$ is not excluded, because of the present phase space limitation. It may be that a 1^{-+} doublet of dominant hybrid and molecular type structure will be required to reconcile all data. Finally, an interesting entrance channel selectivity is noted: in the $\overline{p}p \to \eta\pi^0\pi^0$ annihilation channel, the

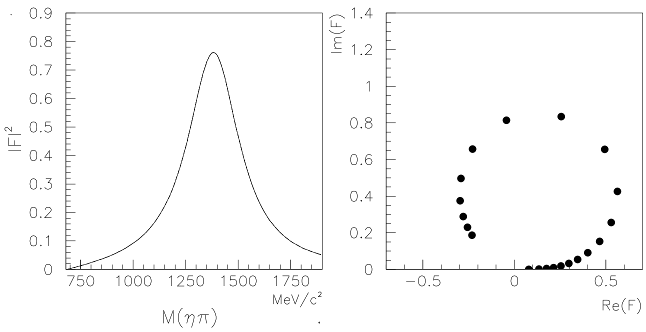

Figure 5: Lhs: $(\eta\pi)_P$ effective range amplitude[6] fitted to the data. Rhs:Corresponding Argand plot, showing the imaginary versus the real part of the effective range amplitude . The range from m = 690 to 1800 MeV/c^2 is divided into equal Δm steps. An almost complete anticlockwise phase rotation is observed.

$J^{PC} = 1^{-+}$ resonance shows up with a smaller relative intensity than in the present channel, but with consistent resonance parameters[7]. In the atomic S-wave, which is dominant in the annihilation at rest, only the ${}^1S_0$ $\overline{p}p$ state and the ${}^3S_1$ $\overline{p}n$ state can decay into the present $\eta\pi\pi$ channels. The observed entrance channel selectivity is probably due to different angular momentum configurations arising from the different initial states.

References

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