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OBSERVATION OF AN EXOTIC $\pi\eta$-STATE IN $\bar{\mathrm{p}}$N-ANNIHILATION

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ABSTRACT

An exotic resonance was observed by the Crystal Barrel Collaboration in the $\bar{\mathrm{p}}$n annihilation channel $\eta\pi^-\pi^0$ and in $\bar{\mathrm{p}}$p-annihilation into $\eta\pi^0\pi^0$. For the former channel antiprotons from LEAR were stopped in a liquid deuterium target, in the latter the data was taken with a liquid and gaseous (12 atm) hydrogen target. The $\eta\pi$-P-wave , carrying quantum numbers (J^{PC}=1^{-+}) not accessible for a quark-antiquark system, is produced with a high rate (11%) in the highly selective $\bar{\mathrm{p}}$n$\rightarrow$ $\eta\pi^-\pi^0$-channel. Together with the two other dominant contributions from $\rho(770)\eta$ and from $a_2(1320)\pi$, it generates a simple pattern in the Dalitz plot of the intensity distribution. The observed interference effects allow to pin down the characteristics of the $\eta\pi$-P-wave. It was found to resonate at a mass of (1400$\pm$20 $\pm$ 20) MeV/c^2 and a with width of (310$\pm$50$^{+50}_{-30}$) MeV/c^2. The state was confirmed in a coupled analysis of data on $\bar{\mathrm{p}}$p$\rightarrow$ $\eta\pi^0\pi^0$ taken with a liquid and gaseous hydrogen target. A contribution of about 4% for the exotic wave was found in these data.

1 Introduction

Mesons with exotic quantum numbers J^{PC} = 0^{--}, 0^{+-}, 1^{-+}, 2^{+-}, ... have necessarily a non-q$\bar{\mathrm{q}}$-structure. They can be glueballs or hybrids, but also diquarkonia or meson molecules. Of course, exotic states cannot mix with ordinary q$\bar{\mathrm{q}}$-mesons.

Thus the indentification of an exotic state exidences unambigously a state with a non-q$\bar{q}$-structure. Here we report on the observation of an exotic meson with $J^{PC} = 1^{-+}$ decaying into $\eta\pi$. The $\eta\pi$ system is attractive for a search for exotics since its P-wave carries exotic quantum numbers. It can be observed in the reactions:

$$\bar{p}n \rightarrow \pi^-\pi^0\eta \ , \qquad \bar{p}p \rightarrow \pi^0\pi^0\eta \tag{1}$$

In pion induced reactions on nucleons evidence for a resonant behaviour in the $\eta\pi$-P-wave was claimed first by the GAMS collaboration [1], in the charge exchange reaction $\pi^-p \rightarrow \eta\pi^0n$; the findings were, however, ambiguous in later analyses [2]. Contributions from an exotic $\pi\eta$-P-wave were also reported from VES [3] which are in a good agreement with the results from BNL [4].

2 Experimental results and Partial Wave Analysis

The data were recorded by stopping antiprotons from LEAR in a liquid deuterium or in a liquid or gaseous hydrogen target. The Crystal Barrel detector is equipped for charged particle tracking in a magnetic field of 1.5 T and is able to measure photons with high precision in a CsI calorimeter covering 98% of 4π [5].

2.1 $\bar{p}n \rightarrow \pi^-\pi^0\eta$

From a total of 8.2 million events taken with a trigger on one charged particle, corresponding to about 10^8 $\bar{p}d$ events, a sample of 52576 $\pi^-\pi^0\eta$ were selected with a proton momentum below 100 MeV. The cut on the proton spectator momentum ensured annihilations on quasi-free neutrons. The background contribution from misidentified events was determined to be 0.5%.

The experimental Dalitz plot is shown in fig.1. A simple pattern is observed which is dominated by a diagonal band due to the $\rho^-(770)$ and two orthogonal bands in the region of the $a_2(1320)$ decaying into $\pi\eta$. The latter shows large modulations due to interference effects.

A partial wave analysis was performed using the isobar model, decomposing the reaction into a series of two-body decays. For the $\bar{p}n \rightarrow \pi^-\pi^0\eta$ channel the model space of possible intermediate states is strongly restricted due to conservation laws. $\bar{p}n$-annihilation restricts the initial state to isospin one; in this final state 2-meson intermediate states with I=0 are forbidden. For S-state capture, intermediate states with $J^P = 0^+$ are in addition excluded. Because of this restriced number of partial waves one can expect a high sensitivity for contributions from 1^{-+} exotics.

In the fits all known resonances with masses inside or close to the allowed phase

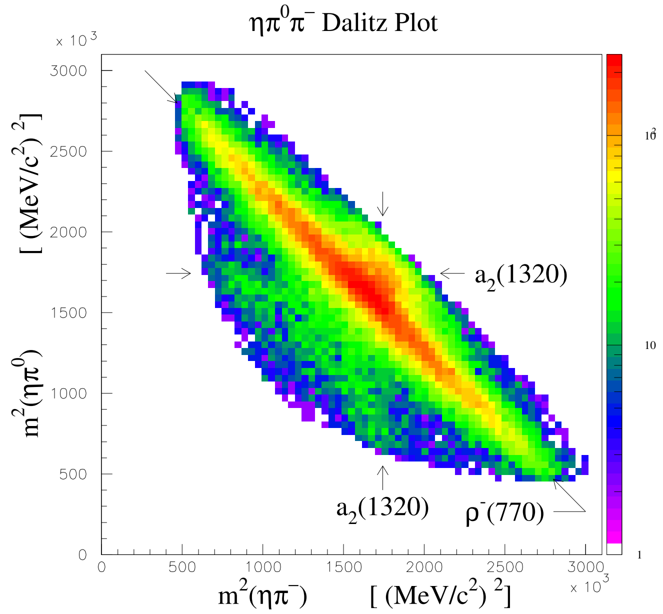

Figure 1: $\pi^-\pi^0\eta$-*Dalitz plot.*

space have been tried using relativistic Breit-Wigner resonance parameterisations. Table 1 shows the result of the partial wave analysis [6]. An exotic 1^{-+}-state was found with a mass of $(1400\pm20\pm20)\,\mathrm{MeV}/c^2$ and a width of $(310\pm50^{+50}_{-30})\,\mathrm{MeV}/c^2$. Its resonance characteristics was clearly established by investigating its interference with the $\rho(770)$ and the $a_2(1320)$. The relative phase of the $\rho(770)$ and the $a_2(1320)$ is determined by their crossing in the Dalitz plot and it is possible to probe the phase of the $\pi\eta$-P-wave relative to both of them. Constructive and destructive interference on opposite sides of the ρ^- band is observed; moving parallel just below the ρ^- band a rise and fall of the constructive term is observed, which reflects the almost complete

Table 1: *Results of the partial wave analysis yielding χ^2=1.29. The rates given for the two incoherent initial states include all interferences of the individual intermediate states, and hence differ from the sums of the individual rates.*

Initial state	channel	Rate (%)	channel	Rate (%)
$^3S_1$ (66.4%)	$\rho^-(770)\eta$	30.0 ± 3.5	$a_2(1320)\pi$	11.1 ± 1.0
	$(1^{-+})\pi$	7.9 ± 1.0		
$^1P_1$ (33.6%)	$[\rho^-(770)\eta]_{l=0}$	10.3 ± 3.0	$[\rho^-(770)\eta]_{l=2}$	17.3 ± 1.2
	$a_2(1320)\pi$	3.8 ± 0.8		
	$[(1^{-+})\pi]_{l=0}$	2.8 ± 1.3	$[(1^{-+})\pi]_{l=2}$	0.5 ± 0.5

phase motion of the $\pi\eta$-resonance. Introduction of further resonances in the fit like the $a_0(980)$, $a_0(1450)$, the $\rho'(1450)$ and the $a_2(1650)$ does not improve the fit quality and their contributions are found to be negligible. Excluding the $\pi\eta$-P-wave from the fits leads to a bad description of the data ($\chi^2 = 3.07$) and to systematic deviations as shown in fig. 2. The observed deviations are related to the missing interferences of the $\pi\eta$-P-wave with the $\rho(770)$ and the $a_2(1320)$.

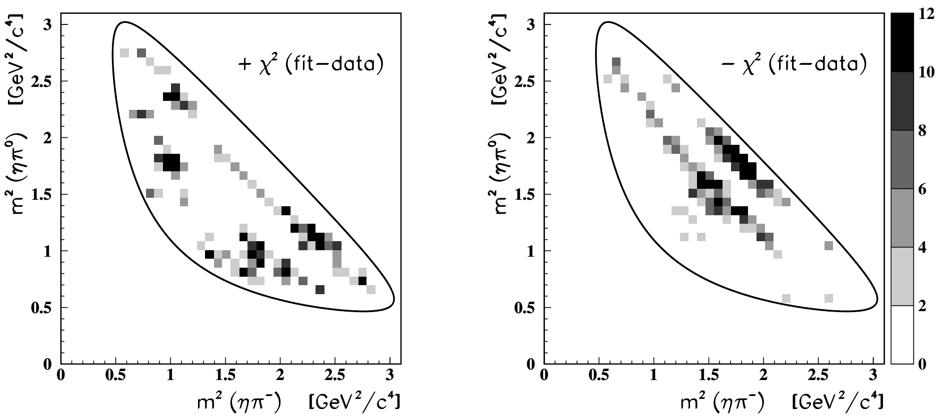

Figure 2: *Deviations between the data and a fit whixh does not include the $\pi\eta$-P-wave but all other allowed resonances. Left: fit exceeds data, right: reverse.*

2.2 The reaction $\bar{\mathrm{p}}\mathrm{p} \to \pi^0\pi^0\eta$ in liquid and gaseous hydrogen

The existence of the exotic state was confirmed in a second analysis of data on $\bar{\mathrm{p}}\mathrm{p} \to \pi^0\pi^0\eta$. A coupled fit of liquid and gaseous hydrogen data on this reaction has been performed to search for the exotic 1^{-+}-state decaying into $\pi^0\eta$. The data was taken in both cases with a trigger asking for no charged particles. The $\mathrm{LH_2}$ data set consists of 280 000 events, the gaseous hydrogen data set of 270 000 events with a background – determined by Monte Carlo simulations – of less than 1%.
The $\pi^0\pi^0\eta$ Dalitz plot for antiprotons annihilating in gaseous $\mathrm{H_2}$ is shown in (fig. 3). The data with antiprotons stopping in liquid $\mathrm{H_2}$ were presented in [7]. While in liquid $\mathrm{H_2}$ the annihilation from initial S-states is dominant, in gaseous hydrogen the annihilation from initial P-states is enhanced.
We first comment on general features of the data. The most prominent signals are a sharp-edged band structure due to the $\mathrm{a_0}(980)$ and a w-shaped structure at the $\mathrm{a_2}(1320)$ mass. In the $\pi^0\pi^0$-mass projection (see fig. 4) the intensity rises slowly and peaks at the $\mathrm{f_0}(980)$; then, at the $\mathrm{K\bar{K}}$-threshold, the intensity falls off rapidly. The

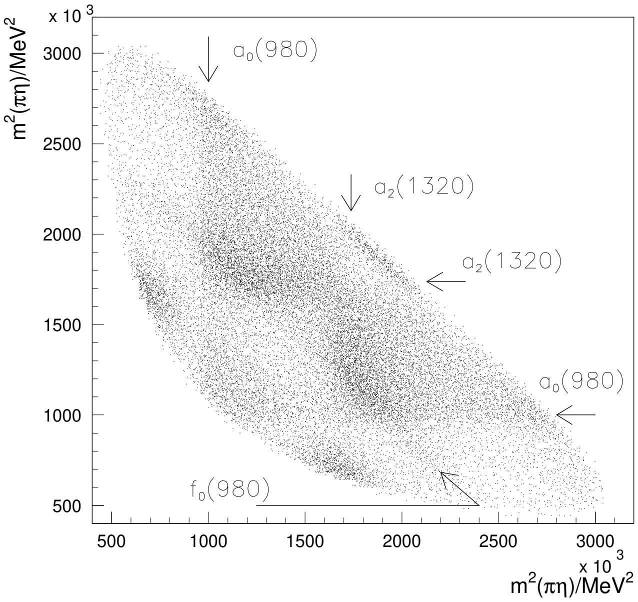

Figure 3: *Dalitz plot of $\bar{p}p$ annihilations at rest into $\pi^0\pi^0\eta$ for antiprotons stopping in gaseous hydrogen at 12 atm (2 entries per event).*

high-mass peak is a reflection from the $a_0(980)$ and $a_2(1320)$ decay angular distributions. The $\eta\pi^0$-mass distribution along the $a_0(980)$ band exhibits a slight depletion at a squared mass of 2.2 GeV^2. This depletion originates from a second isovector state, the $a_0(1450)$ [7]. The $a_0(1450)$ in the vertical band interferes destructively with the $a_0(980)$ in a horizontal band and vice versa. In our former analysis using LH_2 data, P-state annihilation was neglected [7] since inclusion of P-state annihilation would have increased the number of parameters dramatically. From that analysis we got a weak but significant $\pi\eta$-P-wave contribution, no resonance characteristics could be established. Including the gas data introduces additional constraints and allows the inclusion of P-state annihilation [8]. In the fit, the fractions of S- and P-wave contributions in LH_2 and gas data were imposed as calculated in a cascade model [9]. The data provided supportive evidence for the exotic 1^{-+} state, with a mass of 1360 ± 25 MeV and a width of 220 ± 90 MeV, in good agreement with the result from the deuterium data. The quality of the data description it shown in fig. 4. The exotic state is produced at a small rate ($\sim 1\%$ of $\pi^0\pi^0\eta$ in liquid hydrogen) via the $^1S_0$ state but significantly ($\sim 4\%$ of $\pi^0\pi^0\eta$ in gaseous hydrogen) from the $^3P_1$ state. This is a rather large rate considering the fact that the total contribution of the $^3P_1$ state is (20 to 25)% only. In the deuterium data set discussed before

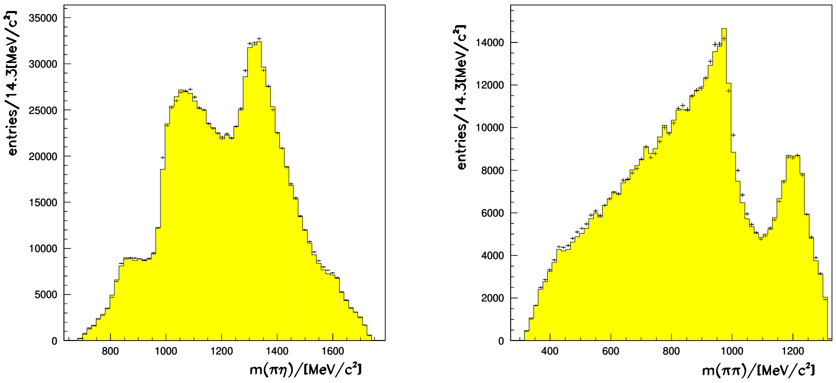

Figure 4: *The $\eta\pi^0$ (left) and $\pi^0\pi^0$ (right) mass distribution for* $\bar{\mathrm{p}}\mathrm{p} \rightarrow \pi^0\pi^0\eta$ *for data from gaseous hydrogen. The shaded area represents the fit.*

its production is larger from $^3\mathrm{S}_1$ than from the $^1P_1$ states. We conjecture that the exotic state is produced more abundantly from spin triplet states and not from spin singlet states.

3 Summary

In the antiproton annihilation data taken by the Crytal Barrel experiment clear evidence for a 1^{-+} state – decaying into $\eta\pi$ – was found. This resonance cannot possibly be a $\mathrm{q}\bar{\mathrm{q}}$-state and since its isospin is one it cannot be a glueball. Thus there remain two possibilities of interpretation: the state could be a hybrid or a 4-quark-state.

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