A study of the $\eta\pi^0$ system produced in the reaction $\pi^- p \to \pi^+\pi^- 4\gamma\ n$ at 18 GeV/c

V.L.Korotkikh and L.I.Sarycheva for the E852 collaboration
Institute of Nuclear Physics, Moscow State University
119899 Moscow, Russia
e-mail: vlk@lav1.npi.msu.su
presented by L.I.Sarycheva

The exclusive reaction $\pi^- p \to \eta\pi^0 n$, $\eta \to \pi^+\pi^-\pi^0$, $\pi^0 \to 2\gamma$ at 18 GeV/c has been studied. A partial wave analysis has been performed on a sample of 18712 $\eta\pi^0 n$ events. A mass dependent fit of the P_+ and D_+ waves and their relative phase gives evidence for a neutral exotic $J^{PC} = 1^{-+}$ state production, where C-parity is a good quantum number.

1. INTRODUCTION

In our previous works [1,2] we reported evidence for an exotic $J^{PC} = 1^{-+}(1400)$ resonance state in the reaction $\pi^- p \to \eta\pi^- p$, $\eta \to 2\gamma$. The Crystal Barrel [3] experiment confirmed this result for $\eta\pi^-$ system in the reaction with antiprotons stopped in liquid deuterium, $\bar{p}n \to \pi^-\pi^0\eta$. Later this group presented evidence [4] for production of the exotic 1^{-+} resonance in the $\eta\pi^0$ system in data on $\bar{p}p$ annihilation at rest into $\pi^0\pi^0\eta$ with $M = (1360 \pm 25)$ MeV/c^2 and $\Gamma = (220 \pm 90)$ MeV/c^2.

The state $\eta\pi^0$ has been studied by the GAMS experiment [5] in the reaction $\pi^- p \to \eta\pi^0 n$, $\eta \to 2\gamma$, $\pi^0 \to 2\gamma$ at 32, 38 and 100 GeV/c. They showed that the P_+ wave mass dependence has a wide bump at $M = 1300$ MeV/c^2. Its form depends strongly on the ambiguous solutions. Resonant motion of the P_+ wave can be seen only at 32 GeV/c, not at 38 or 100 GeV/c.

We have studied the reaction $\pi^- p \to \eta\pi^0 n$, $\eta \to \pi^+\pi^-\pi^0$, $\pi^0 \to 2\gamma$ at 18 GeV/c. The important and obvious characteristic of the $\eta\pi^0$ system unlike $\eta\pi^-$ system is that C-parity is a good quantum number. Thus it is possible to study the exotic (non $q\bar{q}$) state with quantum numbers $J^{PC} = 1^{-+}$. The other distinguishing feature of the charge exchange reaction $\pi^- p \to \eta\pi^0 n$ is that, unlike $\eta\pi^- p$ production, the production mechanism cannot involve the exchange of an I=0 system and thus pomeron exchange is ruled out. Finally, it is important to note that, from the experimental point of view, in the reaction $\pi^- p \to \pi^+\pi^- 4\gamma n$ we can define the interaction point by the charged tracks and convince ourselves that the event is in the target region. This is not possible in the all neutral final state when the η decays to 2 photons.

The data for this analysis was obtained in the E852 experiment [6] at the Alternating Gradient Synchrotron (BNL USA) during 1995. Using an 18 GeV/c π^- beam interacting with liquid hydrogen target, a total of 750 million triggers were acquired of which 108 million were of a type designed to enrich the exclusive final state events $\pi^- p \to \pi^+\pi^- 4\gamma n$. A total 6 million events of this type were fully reconstructed.

The data were kinematically fitted to select events consistent with an $\eta\pi^0 n$ hypothesis. Requiring a minimum acceptable confidence level of 10% for this hypothesis, a total of 20674 $\eta\pi^0 n$ events remained. An additional cut in the beam region was applied to remove events where the drift chamber efficiency was low. After that cut, 18712 $\eta\pi^0$ events remained for the partial wave analysis (PWA).

The dependence of $\eta\pi^0$ system mass shows two well-defined peaks at 1.0 and 1.3 MeV/c^2. We fit the t'-dependence of the acceptance corrected data for all masses using the expression

$$N(t') = n_1 e^{-b_1|t'|} + n_2|t'|e^{-b_2|t'|}$$

and find the values of parameters

$$b_1 = (5.5 \pm 1.6)(\mathrm{GeV/c})^2, \qquad b_2 = (5.40 \pm 0.04)(\mathrm{GeV/c})^2.$$

2. PARTIAL WAVE ANALYSIS

The PWA [7] was performed on the sample of 18712 $\eta\pi^0 n$ events (note that for $\eta\pi^- p$ events [1] there were 47200 events) for $0.78 < M(\eta\pi^0) < 1.72$ GeV/c^2 and $0. < |t'| < 1.0$ (GeV/c)^2 in $\Delta M = 40$ MeV/c^2 mass bins. The PWA has been done using 7 amplitudes: S_0,P_0, P_-, D_0, D_- (unnatural parity exchange, UNPE) and P_+, D_+ (natural parity exchange). See notations and details in [2].

The D_+ and P_+ waves are the main contributions to the total intensity. The ratio of P_+ and D_+ wave intensities is greater (about 20%) than for the $\eta\pi^-$ system [1]. The same ratio is observed for the $\eta\pi^0$ system in the GAMS analysis [5]. The contribution from the UNPE waves is smaller except for the D_0 wave (about 20%), but the spread of the UNPE ambiguous solutions is larger than for the $\eta\pi^-$ system [2]. For this reason, the shape of the P_+ intensity distribution depends strongly on solution. The phase motion between the P_+ and the D_+ waves is very similar to that in the $\eta\pi^-$ system [1] as well as that of the $\eta\pi^0$ system of GAMS [5]. The goodness-of-fit for the PWA is good. The comparison of the data moments $H(LM)$, ($L \leq 2$, $M \leq 2$) and their prediction from the PWA gives $\chi^2/dof = 0.18$.

3. MASS DEPENDENT ANALYSIS

We simultaneously fit the intensities of the D_+ and P_+ waves and their relative phase in the region $1.02 < M(\eta\pi^0) < 1.74$ MeV/c^2. The central values for the intensities and phases are taken from the PWA as the average values of the ambiguous solutions. The errors are calculated from the average error matrix. The mass dependent fit includes a Breit-Wigner (BW) amplitude for the D_+ wave with a second order polynomial background; a BW amplitude for the P_+ wave (resonant hypothesis) and a mass-independent production phase. (See details in [2].) For the nonresonant hypothesis we used a Gaussian intensity distribution for the P_+ wave and a linear mass dependence for the production phase.

The result of the fit with the resonant hypothesis ($\chi^2/dof = 0.92$) is shown in Fig. 1. There is no need to introduce a mass dependence for the production phase in the resonant

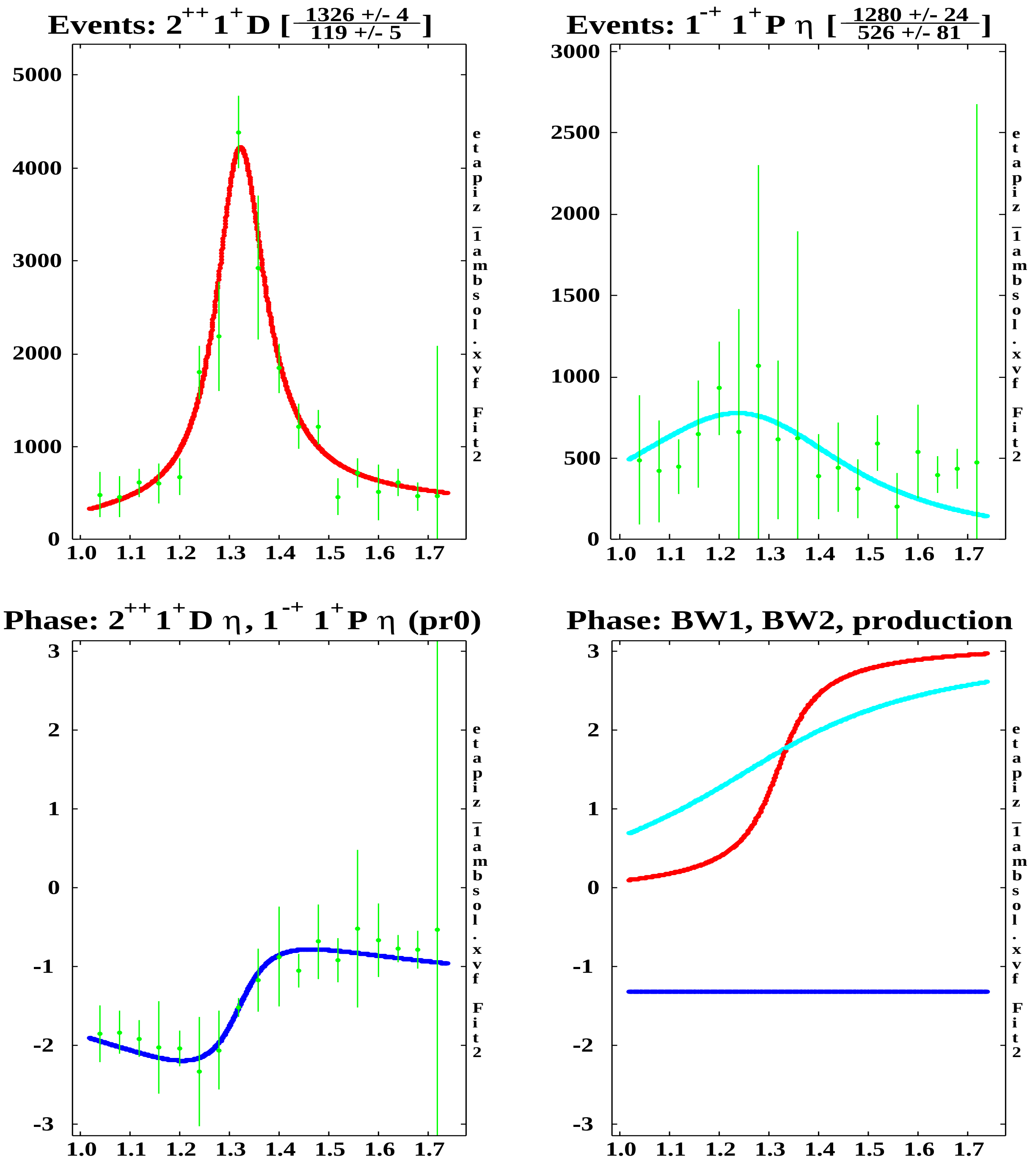

Figure 1. A coupled mass-dependent fit of the D_+ and P_+ waves from the PWA results. Shown are the fitted intensity distributions for $D_+(2^{++})$ and $P_+(1^{-+})$ waves (top left and top right) and their phase difference (left lower figure). The lines on the right lower figure show the fitted BW phase of the 2^{++} state (strong motion), the 1^{-+} state (weak motion) and the mass independent production phase.

hypothesis. On the contrary, for the nonresonant hypothesis, there is a large slope parameter for the production phase, $-2.73\ rad/GeV$, which is inconsistent with Regge-pole phenomenology.

The parameters of the fitted BW amplitudes for the 2^{++} state (a_2^0 meson) are

$$M(a_2^0) = (1326 \pm 4^{+24}_{-56})\ \mathrm{MeV/c^2},$$

$$\Gamma(a_2^0) = (119 \pm 5^{+140}_{-56})\ \mathrm{MeV/c^2},$$

and for the exotic 1^{-+} state (π_1^0 meson)

$$M(\pi_1^0) = (1280 \pm 24^{+70}_{-50})\ \mathrm{MeV/c^2},$$

$$\Gamma(\pi_1^0) = (526 \pm 81^{+34}_{-326})\ \mathrm{MeV/c^2}.$$

The systematic errors for the mass and width are taken from the range of ambiguous solutions.

We draw attention to the mass and width of the a_2-resonance which are very close to Particle Data Group [8] values: $M(a_2) = (1318.1 \pm 0.7)$ MeV/c^2, $\Gamma(a_2) = (107 \pm 5)$ MeV/c^2. Our measured a_2 width is larger due to the resolution effects. We can also compare with the parameters for exotic 1^{-+} of $\eta\pi^-$ system from our work[1]:

$$M(\pi_1^-) = (1370 \pm 16^{+50}_{-30})\ \mathrm{MeV/c^2},$$

$$\Gamma(\pi_1^-) = (385 \pm 40^{+65}_{-100})\ \mathrm{MeV/c^2}.$$

4. CONCLUSIONS

The fitted value for $M(\pi_1^0)$, the mass of the exotic 1^{-+} from $\eta\pi^0$ decay is somewhat lower than that from $\eta\pi^-$ decay and $\Gamma(\pi_1^0)$ is greater, but the large systematic uncertainties in these values when the ambiguous solutions are taken into account make them compatible within errors.

Our study of the $\eta\pi^0$ system and the Crystal Barrel result [4] give evidence for the neutral exotic $J^{PC} = 1^{-+}$, where C-parity is a good quantum number.

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