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SPIN-PARITY ANALYSIS OF $\eta\pi^o\pi^o$-SYSTEM IN π^-p CHARGE EXCHANGE REACTION AT 100 GeV/c BY ZEMACH METHOD

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Abstract

Alde D., Binon F., Donskov S.V. et al. Spin-parity analysis of $\eta\pi^o\pi^o$-system in π^-p charge exchange reaction at 100 GeV/c by Zemach method: IHEP Preprint 96-39. – Protvino, 1996. – p. 9, figs. 3, tables 2, refs.: 19.

A spin-parity analysis of $\eta\pi^o\pi^o$-system produced in the charge exchange $\pi^-p \to \eta\pi^o\pi^o n$ reaction is performed in a mass range up to 1,9 GeV. The data have been collected with GAMS-4000 multiphoton spectrometer in 100 GeV/c secondary π^- beam of SPS at CERN. Clear peaks are observed in the mass spectra, corresponding to the $\eta(1295)$ and $\iota/\eta(1440)$ mesons in the pseudoscalar sector, and to the $D/f_1(1285)$ meson in the axial-vector sector. Their masses and widths are in a good agreement with the world average values. Several decay branching ratios as well as the production cross sections of these mesons are measured. The $\eta(1295)$ decay to $\eta\pi^o\pi^o$ is dominated by the $a_0(980)\pi^o$ subchannel. Contrary to this, the $\iota/\eta(1440) \to a_0(980)\pi^o$ decay is rather week, the $\eta(\pi^o\pi^o)_S$ subchannel dominates in the iota to $\eta\pi^o\pi^o$ decay. This is an argument towards the iota assignment as an exotic meson with a strong valence gluon component.

Аннотация

Алди Д., Бинон Ф., Донсков С.В. и др. Анализ спин-четности $\eta\pi^o\pi^o$-систем, образованных в зарядовообменной π^-p-реакции при импульсе 100 ГэВ/с, методом Земаха: Препринт ИФВЭ 96-39. – Протвино, 1996. – 9 с., 3 рис., 2 табл., библиогр.: 19.

Проведен анализ спин-четности $\eta\pi^o\pi^o$-систем, образованных в зарядовообменной реакции $\pi^-p \to \eta\pi^o\pi^o n$ в области $\eta\pi^o\pi^o$-масс до 1,9 ГэВ. Измерения выполнены на многофотонном спектрометре ГАМС-4000 в пучке π^--мезонов с импульсом 100 ГэВ/с ускорителя SPS CERN. В массовых спектрах наблюдаются четкие пики, соответствующие $\eta(1295)$- и $\iota/\eta(1440)$-мезонам в псевдоскалярном секторе и $D/f_1(1285)$-мезону в аксиально-векторном секторе. Массы и ширины резонансов находятся в хорошем согласии со средними мировыми величинами. Измерен ряд относительных ширин распадов этих мезонов в сечения их образования. В распаде $\eta(1295) \to \eta\pi^o\pi^o$ преобладает $a_0(980)\pi^o$-канал. В отличие от этого, распад $\iota/\eta(1440) \to a_0(980)\pi^o$ малоинтенсивен, в распаде ι-мезона на $\eta\pi^o\pi^o$ доминирует $\eta(\pi^o\pi^o)_S$ канал. Это является аргументом в пользу интерпретации ι-мезона как частицы с сильной компонентой валентных глюонов.

Introduction

The aim of this paper is a spin-parity analysis of $\eta\pi^o\pi^o$-system produced in the charge exchange reaction[1]

$$\pi^- p \to \eta\pi^o\pi^o n \tag{1}$$

in 1 GeV to 1,9 GeV mass region, where several pseudoscalar ($J^{PC} = 0^{-+}$) and axial-vector (1^{++}) mesons have been observed in different decay channels [2]. With recent development of E/ι problem [3], the pseudoscalar sector shows an intriguing structure: among three 0^{-+} states observed in the above mass range the lightest one, $\eta(1295)$, may be assigned to a radial excitation of the η-meson, while one of two other mesons with ≈ 1400 MeV and ≈ 1490 MeV masses may be considered to be a η' radial excitation and the other one then be a candidate to an exotic (non-$q\bar{q}$) state.

The results of the partial wave analysis (PWA) of $\eta\pi^+\pi^-$-system have been reported in the $\pi^- p \to \eta\pi^+\pi^-$n reaction at 8.06 GeV/c and 8.95 GeV/c at KEK [4]. The $\eta\pi^o\pi^o$-system has not yet been studied in the π^-p charge exchange reaction, though $\eta\pi^o\pi^o$ is known as a good system for the PWA because odd J^P waves in the $\pi^o\pi^o$-subsystem should be omitted due to π^o identity and therefore the number of waves entering the PWA of $\eta\pi^o\pi^o$-system is strongly reduced as compared to that of $\eta\pi^+\pi^-$-system.

The experiment on a study of reaction (1) with η and π^o decaying into two photons (six photons in total) has been carried out with the GAMS–4000 multiphoton spectrometer [5] in 100 GeV/c secondary π^--beam of SPS (NA12 experiment at CERN). The GAMS to the hydrogen target distance was equal to 15 m. The general layout of the experiment, details of the GAMS–4000 construction and calibration as well as the data treatment procedures have been described elsewhere [5,6].

At the first stage of data treatment a modified version of SLAC–Berkeley program [7] was used for the PWA of reaction (1) on a refined event set [1]. In present work a simplified method based on the Zemach analysis of Dalitz plots in various $\eta\pi^o\pi^o$ mass bins is used.

[1]The first results of the partial wave analysis have been reported by T.Tsuru [1].

The criteria of event selection are changed from [1] to increase statistics and to suppress low-$|t|$ background processes.

1. Selection of $\eta\pi^o\pi^o$ events, mass spectra

The separation of $\eta\pi^o\pi^o$ events from $3\pi^o$ and $\eta\eta\pi^o$ events detected simultaneously in the experiment is performed by means of kinematical analysis of all 6γ-events based on 4C-fit (the masses of a recoil neutron, η and π^o mesons are fixed) [8,9]. More than 60,000 pure $\eta\pi^o\pi^o$ events are retained for further analysis. An additional cut, $-t > 0,15$ (GeV/c)^2, is applied to reduce a nonresonant continuum in the E/ι mass region.

The mass spectrum of selected $\eta\pi^o\pi^o$ events is shown in fig. 1. Besides the dominant peak of η'-meson, two other peaks are clearly seen in this spectrum: the first one in the $f_1(1285)$, $\eta(1295)$ region and the second one in the $f_1(1420)$, $\eta(1440)$ region. A correction for the detection efficiency does not change significantly the shape of mass spectrum.

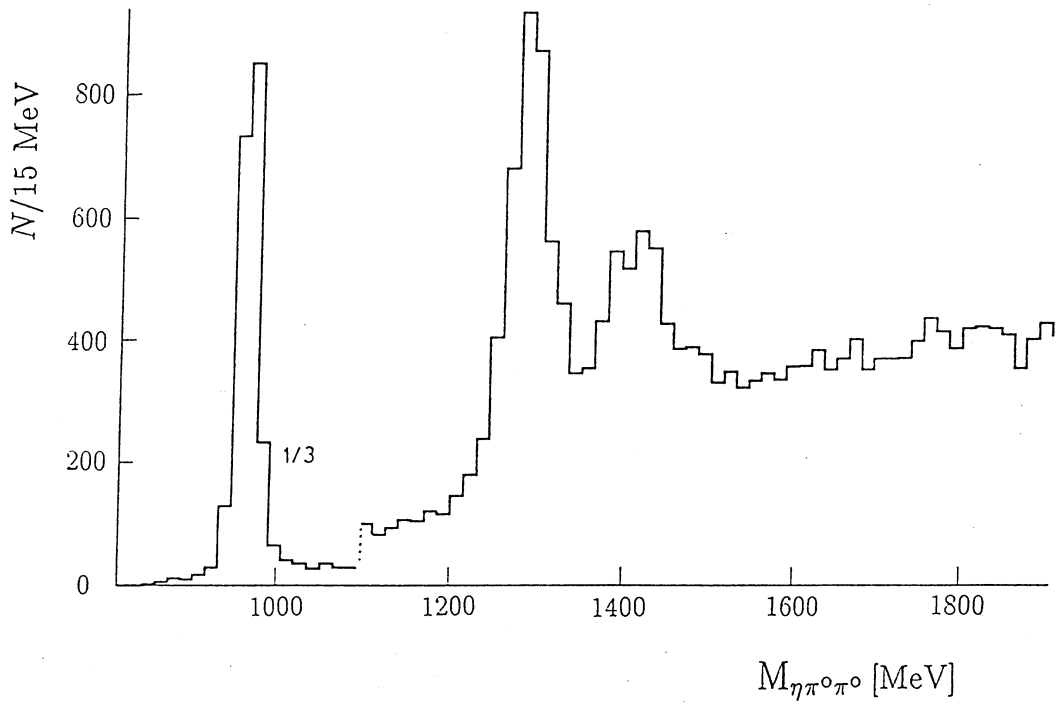

Fig. 1. Mass distribution of $\eta\pi^o\pi^o$ events produced in reaction (1) at 100 GeV/c. Here and further $-t > 0.15$ (GeV/c)^2.

The spin-parity analysis has been performed independently in 30 MeV $\eta\pi^o\pi^o$ mass bins in 1020 MeV to 1920 MeV interval using about 19,000 events in total. In the mass distribution of selected events no resonant structure is seen in the $\pi^o\pi^o$-subsystem, while clear peaks are observed in the $\eta\pi^o$-subsystem at 980 MeV and 1320 MeV [1]. These are naturally identified, according to the peak positions and the widths, with the intermediate $a_0(980)$ and $a_2(1320)$ mesons produced in the last subsystem.

2. Spin-parity analysis of $\eta\pi^o\pi^o$-system

The spin-parity analysis of the $\eta\pi^o\pi^o$-system has been performed on a basis of the isobar model [10] using Zemach representation [11] for the decay amplitudes. The only Dalitz variables of $\eta\pi^o\pi^o$-system are used in the analysis (see below). For fitting the event distributions the maximum-likelihood method is applied.

In a framework of the isobar model the decay amplitude of the system with J^{PC} spin-parity is composed of quasi-two-body amplitudes using Zemach spin-tensors $Z_{J^{PC}}$ and dynamical factors F, which are Breit-Wigner functions for the intermediate resonances in dimeson subsystems[2]

$$A_{J^{PC}} = \sum_k \alpha^k_{J^{PC}} \cdot A^{L_k}_{J^{PC}} = \sum_k \alpha^k_{J^{PC}} \cdot Z^{L_k}_{J^{PC}}(p^{k_1}, p^{k_2}, p^{k_3}) \cdot F^{L_k}_k(p^{k_1}, p^{k_2}). \quad (2)$$

Here the summation is performed over the k-channel amplitude decompositions, $\alpha^k_{J^{PC}}$ is a complex intensity of the elementary amplitude $A^{L_k}_{J^{PC}}$;[3] L_k is a relative angular momentum of the dimeson subsystem, which includes k_1 and k_2 mesons, p^{k_i} is a 4-momentum of k_i-meson in the $\eta\pi^o\pi^o$-system. The amplitudes were constructed symmetrically over the π^o permutations. It is worth noting that the interference occurs only between amplitudes with the same spin-parity. Thus the Dalitz plot density can be expressed in a form:

$$I_o(m^2_{13}, m^2_{23}) = \sum_{J^{PC}} \mid A_{J^{PC}} \mid^2 . \quad (3)$$

The detected event distribution over the Dalitz plot is defined by the equation:

$$I_{acc}(\tilde{m}^2_{13}, \tilde{m}^2_{23}) = \int dm^2_{13} dm^2_{23}\ I_o(m^2_{13}, m^2_{23}) \cdot \varepsilon(m^2_{13}, m^2_{23}) \cdot \varrho(\tilde{m}^2_{13} - m^2_{13}, \tilde{m}^2_{23} - m^2_{23}), \quad (4)$$

where the measured variables are marked with *tilde*, $\varepsilon(m^2_{13}, m^2_{23})$ is the detection efficiency for the events with the given masses of meson pairs and $\varrho(\tilde{m}^2_{13} - m^2_{13}, \tilde{m}^2_{23} - m^2_{23})$ is the mass resolution function of the GAMS detector.

The detection efficiency as well as the mass resolution have been calculated for each $\eta\pi^o\pi^o$ mass bin by the Monte Carlo method. The detection efficiency (about 50%) is rather flat function of masses in the present experiment. It does not influence the PWA results, whereas the account of mass resolution improves essentially the fit quality.

The maximum likelihood function used in the Dalitz plot fitting is based on an assumption that the event number in each bin of the plot follows the Poisson distribution:

$$-\,ln\ P = -\sum_{ij}(N_{ij} \ln \mu_{ij} - \mu_{ij}), \quad (5)$$

where N_{ij} is the detected event number in the ij bin of Dalitz plot and μ_{ij} is its expected value:

[2] We assume that $\pi^o\pi^o$-subsystem is produced in reaction (1) with zero total isospin.

[3] Here and further on the normalization $\int dm^2_{13} dm^2_{23}\ |Z^{L_k}_{J^{PC}}(p^{k_1}, p^{k_2}, p^{k_3}) \cdot F^{L_k}_k(p^{k_1}, p^{k_2})|^2 = 1$ is applied.

$$\mu_{ij} = \int d\tilde{m}^2_{13} d\tilde{m}^2_{23}\ I_{acc}(\tilde{m}^2_{13}, \tilde{m}^2_{23}). \qquad (6)$$

The integration is carried out over the ij bin of the plot.

An initial set of elementary amplitudes used in the spin-parity analysis is defined by resonances (isobars) in dimeson subsystems, as well as by the highest spin of $\eta\pi^o\pi^o$ states whose contribution can still be important in the relevant $\eta\pi^o\pi^o$ mass region. At least four isobars may contribute significantly to the dimeson spectra: $a_o(980)$ and $a_2(1320)$ in the $\eta\pi^o$-subsystem and f_0, or $(\pi^o\pi^o)_S$, and $f_2(1270)$ in that of $\pi^o\pi^o$ [1]. As for the highest spin value, all the states with $J \leq 2$ have been taken into account.

The Breit-Wigner functions with the table parameters [2] were used as dynamical factors in equation (2) for the $a_o(980)$, $a_2(1320)$ and $f_2(1270)$ resonances, while the $\pi^o\pi^o$ S-wave phase shift parametrization [12,13] was used for the f_0.

Initially all elementary amplitudes were included in the fit. But then the amplitudes with the $\mid \alpha^k_{J^{PC}} \mid^2$ compatible with zero within a standard deviation have been discarded. As a result, eight amplitudes[4] are left for the Dalitz plot fitting in a mass range up to 1,9 GeV: $0^- a_0\pi^o S$, $0^- f_0\eta S$, $1^+ a_0\pi^o P$, $1^+ f_0\eta P$, $1^+ a_2\pi^o P$, $1^+ f_2\eta P$, $2^- a_2\pi^o P$ and $2^- f_2\eta P$ (the elementary amplitudes with a_2 and f_2 resonances were introduced in the fit starting from 1400 MeV of the $\eta\pi^o\pi^o$ mass). Hence in our PWA model ($J \leq 2$) the $\eta\pi^o\pi^o$-system in the above mentioned mass range is produced in reaction (1) mainly in three J^{PC} states: 0^{-+}, 1^{++} and 2^{-+}.

The mass spectra of first two amplitudes are presented in fig. 2. The 2^{-+} spectrum (not shown) is structureless and contributes to the E/ι region much less than 0^{-+} and 1^{++} amplitudes.

The 0^{-+} amplitude shows two clear peaks, at 1300 MeV and 1400 MeV. The first one is identified with the $\eta(1295)$-meson and the second one with the $\eta(1440)$-meson (former $\iota(1420)$). In the 1^{++} amplitude the only peak near 1300 MeV is definitely seen. It is identified with the $f_1(1285)$-meson (former $D(1285)$-meson).

The mass spectra of significant $J^P xyL$ amplitudes are presented in fig. 3. Peaks of the $\eta(1295)$, $\iota/\eta(1440)$ and $f_1(1285)$ mesons are clearly seen. As for the $f_1(1420)$-meson, while it gives no signal in the 1^{++} mass spectrum (fig. 2), an enhancement is visible in the $1^+ a_0\pi^o P$ amplitude around 1420 MeV (fig. 3).

The comparison of fig. 2 and fig. 3 shows that in the $\eta(1295) \to \eta\pi^o\pi^o$ decay the $a_0(980)\pi^o$ subchannel dominates in spite of a very limited phase space. Contrary to this, the $\iota/\eta(1440) \to a_0(980)\pi^o$ decay is rather week (while two times larger phase space is available), the $f_0\eta$ subchannel dominates in the iota to $\eta\pi^o\pi^o$ decay. This is a strong argument towards a gluonic iota nature: both the low mass S-wave $\pi\pi$-system and the η-meson are strongly coupled to gg-pair [14-17] and the decay to $\eta(\pi\pi)_S$ should be enhanced for mesons built with valence gluons (glueballs, hybrids).

The mass spectra in fig. 2 have been fitted with three Breit-Wigners (convoluted with the spectrometer mass resolution) and incoherent polynomial continua.

[4]For Zemach amplitudes we use the $J^P xyL$ notations, where J^P are the spin-parity, x is an isobar, y is a bachelor meson, and L is the x and y angular momentum.

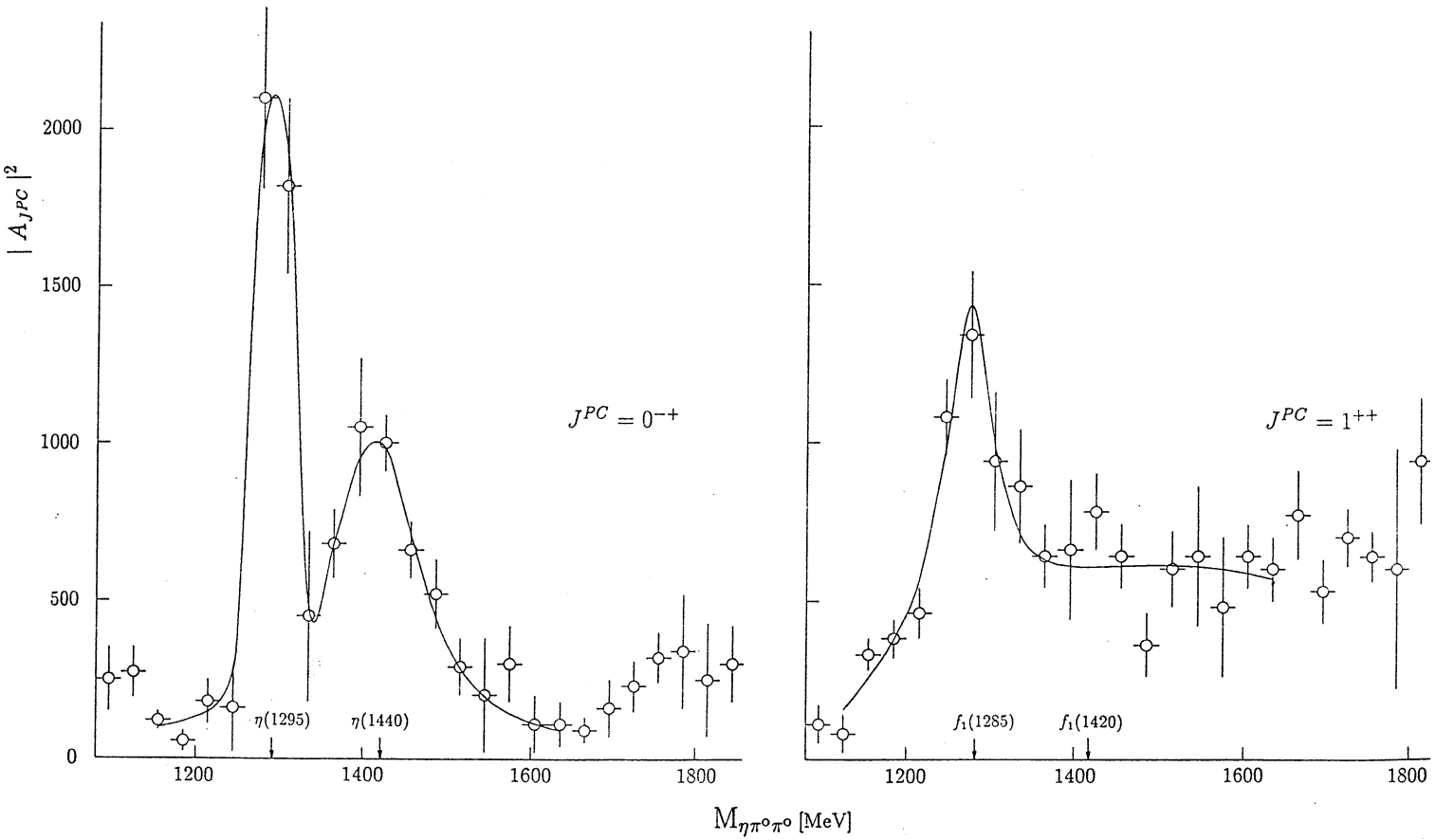

Fig. 2. Mass spectra of the J^{PC} amplitudes: 0^{-+} and 1^{++}. Here and in the next figure the vertical scale shows the efficiency of corrected event numbers in 30 MeV mass bins. The arrows point to the table values of the $\eta(1295)$, $\iota/\eta(1440)$, $f_1(1285)$ and $f_1(1420)$ masses [2]. The fitting curves, with free resonance parameters, are described in text.

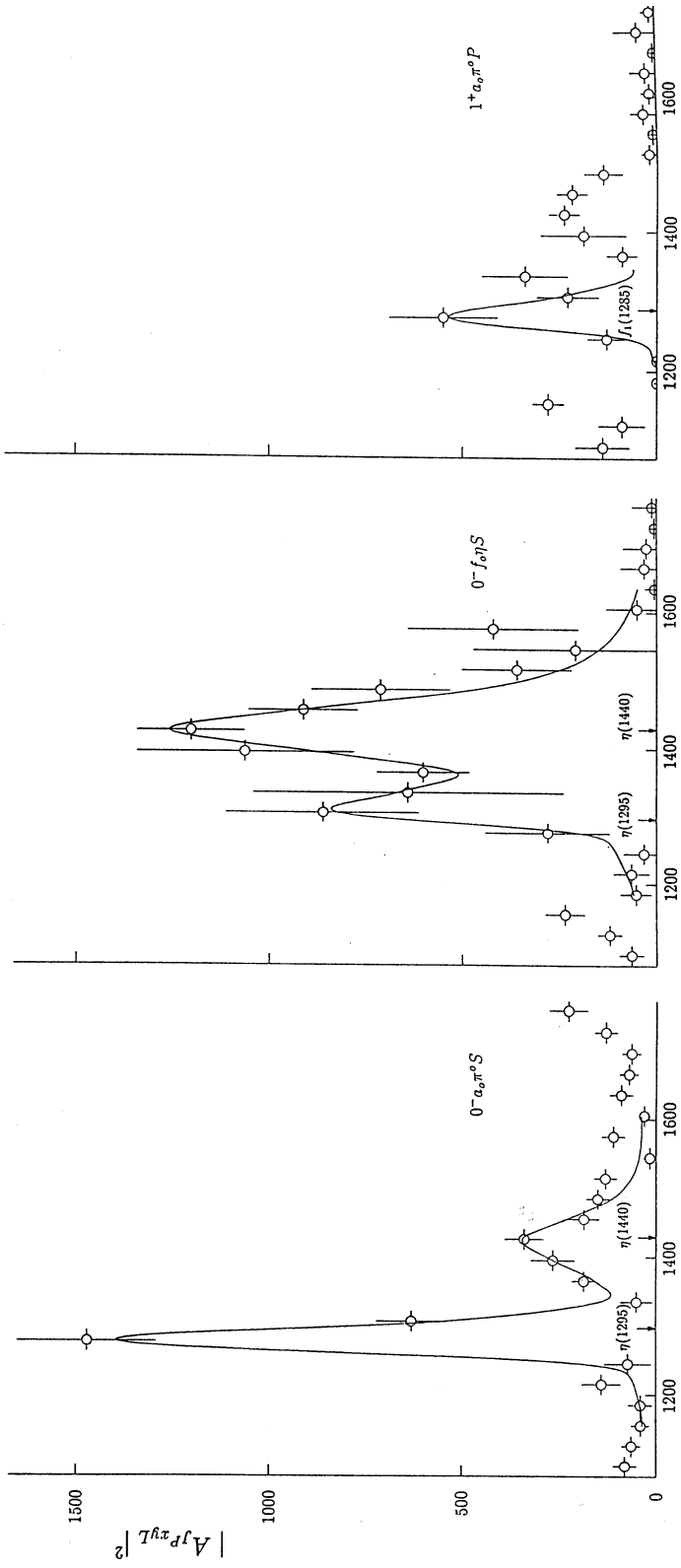

Fig. 3. Mass spectra of the $J^P xyL$ amplitudes: $0^- a_0\pi^o S$, $0^- f_0\eta S$ and $1^+ a_0\pi^o P$.

The results obtained for the resonance parameters are collected in Table 1. The parameters are in agreement with the world average values [2]. The $\eta(1295)$ peak width is governed by the instrumental resolution. In this case we derived a 90% C.L. upper limit for the $\eta(1295)$ width.

Table 1.

Meson	Mass, in MeV	Width, in MeV
$\eta(1295)$	1299 ± 4	< 40
$\iota/\eta(1440)$	1424 ± 6	85 ± 18
$f_1(1285)$	1284 ± 6	55 ± 18

The contributions of different subchannels to the $\eta\pi^o\pi^o$ decays of resonances

$$R(k/\eta\pi^o\pi^o) = \frac{|\alpha^k_{J^PC}|^2}{\sum_n |\alpha^n_{J^PC}|^2} \tag{7}$$

are estimated from the mass spectra of the corresponding $J^P xyL$ amplitudes (fig. 3). Three Breit-Wigners with parameters statistically consistent with the table values [2] are used to fit the spectra. The obtained R values are presented in Table 2.

Table 2.

Meson	$R(a_0\pi^o/\eta\pi^o\pi^o)$	$R(f_0\eta/\eta\pi^o\pi^o)$
$\eta(1295)$	0.65 ± 0.10	0.35 ± 0.10
$\iota/\eta(1440)$	0.19 ± 0.04	0.81 ± 0.04
$f_1(1285)$	0.28 ± 0.07	–

The ratio of two iota branchings,

$$BR(\iota \to \eta(\pi^o\pi^o)_S)/BR(\iota \to a_0\pi^o, a_0 \to \eta\pi^o) = 4.3 \pm 1.2, \tag{8}$$

is by an order of magnitude higher than that of $\eta(1295)$, which equals 0.54 ± 0.22.

3. Production cross sections

The production cross sections of the resonances have been normalized to the cross section of the $\eta'(958)$-meson, $\sigma(\pi^- p \to \eta' n) \cdot BR(\eta' \to \eta\pi^o\pi^o) = 42 \pm 6$ nb at 100 GeV/c and $-t > 0.15$ (GeV/c)^2, which follows from [2,18,19].

The obtained cross section values are:

$$\begin{aligned}
\sigma(\pi^- p \to \eta(1295) n) \cdot BR(\eta(1295) \to \eta\pi^o\pi^o) &= 12 \pm 3\ nb \qquad (2100\ events),\\
\sigma(\pi^- p \to \eta(1440) n) \cdot BR(\eta(1440) \to \eta\pi^o\pi^o) &= 12 \pm 3\ nb \qquad (2200\ events),\\
\sigma(\pi^- p \to f_1(1285) n) \cdot BR(f_1(1285) \to \eta\pi^o\pi^o) &= 8 \pm 2\ nb \qquad (1400\ events).
\end{aligned} \tag{9}$$

Conclusions

We summarize that in the $\pi^- p \to \eta\pi^o\pi^o n$ reaction at 100 GeV/c and $-t > 0.15$ (GeV/c)^2 clear signals of $\eta(1295)$, $\iota/\eta(1440)$ and $D/f_1(1285)$ mesons are observed in the $\eta\pi^o\pi^o$ mass spectra of the corresponding J^{PC} amplitudes. The measured parameters of all resonances are in a good agreement with the world average values. In the $\eta(1295) \to \eta\pi^o\pi^o$ decay the $a_0\pi^o$ subchannel dominates, whereas it is rather weak in the $\iota/\eta(1440)$ case (in spite of a much larger phase space available in the iota decay); here the $\eta(\pi^o\pi^o)_S$ subchannel dominates giving an argument to consider the iota to be a meson with a strong valence gluon component.

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Анализ спин-четности $\eta\pi^o\pi^o$-систем, образованных в зарядовообменной π^-p-реакции при импульсе 100 ГэВ/с, методом Земаха.

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