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Study of diffractive reaction $\pi^- A \to \eta\eta\pi^- A$ at the momentum $P_{\pi^-} = 37\ GeV/c$.

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Аннотация

Амелин Д.В. и др. Изучение дифракционной реакции $\pi^- A \to \eta\eta\pi^- A$ при импульсе $P_{\pi^-} = 37\ ГэВ/c$: Препринт ИФВЭ 95-112. – Протвино, 1995. – 7 с., 5 рис., библиогр.: 17.

Проведен парциально-волновой анализ системы $\eta\eta\pi^-$, образующейся в реакции $\pi^- A \to \eta\eta\pi^- A$ на бериллиевой мишени при импульсе пучка $P_{\pi^-} = 37\ GeV/c$. Показано, что в диапазоне масс $M_{\eta\eta\pi^-} = 1.5 \div 2.0$ ГэВ доминирует волна $J^{PC} = 0^{-+}$ в канале $a_0^-(980)\eta$, имеющая резонансное поведение с параметрами: $M = 1840 \pm 10(\text{стат.}) \pm 10(\text{сист.})$ МэВ, $\Gamma = 210 \pm 30(\text{стат.}) \pm 30(\text{сист.})$ МэВ. Структура в спектре масс $\eta\eta$ описывается введением изобары с квантовыми числами $J^P = 0^+$ и параметрами $M \approx 1460$ МэВ, $\Gamma \approx 100$ МэВ.

Abstract

Amelin D.V. et al. Study of diffractive reaction $\pi^- A \to \eta\eta\pi^- A$ at momentum $P_{\pi^-} = 37\ GeV/c$: IHEP Preprint 95-112. – Protvino, 1995. – p. 7, figs. 5, refs.: 17.

The partial-wave analysis of the system $\eta\eta\pi^-$ produced in the reaction $\pi^- A \to \eta\eta\pi^- A$ on target at the beam momentum $P_{\pi^-} = 37\ GeV/c$ is performed. It is shown that 1) the wave with $J^{PC} = 0^{-+}$ in $a_0^-(980)\eta$ channel dominates in the $M_{\eta\eta\pi^-} = 1.5 \div 2.0$ GeV mass range. It has resonant behaviour with parameters $M = 1840 \pm 10(\text{stat.}) \pm 10(\text{syst.})$ MeV, $\Gamma = 210 \pm 30(\text{stat.}) \pm 30(\text{syst.})$ MeV; 2) the structure in $\eta\eta$ mass spectrum is described by including in PWA an isobar with quantum numbers $J^P = 0^+$ and parameters $M \approx 1460$ MeV, $\Gamma \approx 100$ MeV.

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1. Introduction

This paper is devoted to the experimental study of $\eta\eta\pi^-$ system produced with π^- beam at 37 GeV/c on a target in the reaction

$$\pi^- A \to \eta\eta\pi^- A. \tag{1}$$

The experiment was performed in the VErtex Spectrometer (VES) setup on IHEP U-70 accelerator at Protvino.

Some results on the reaction (1) with smaller statistics were reported already [1]. A resonance-like peak was observed at $M \approx 1.8\ GeV$ in the effective mass spectrum of $\pi^-\eta\eta$ system. Its quantum numbers were not determined because of the lack of statistics. In the $\eta\eta$ mass spectrum a peak at $M \approx 1.45\ GeV$ was observed.

The $\eta\eta\pi$ system was also studied in $p\bar{p}$ annihilation [2,3,4,5].

Significant increase of statistics in the present work in comparison with [1] allows to fulfill a partial wave analysis of the $\eta\eta\pi^-$ system and to determine its quantum numbers.

2. Events selection

The VES [1] setup is a wide-aperture magnetic spectrometer with γ-detector and multichannel threshold Cerenkov counter for secondary particles identification. The trigger base scheme demands at least two charged particles in the forward hemisphere and no charged particles with large angle with respect to the beam direction.

One of the η-mesons of the reaction (1) was detected by $\pi^+\pi^-\pi^0$ decay mode and another one by $\gamma\gamma$ decay mode. To select this reaction several criteria were applied like:

- Three charged tracks (giving total charge equal to -1) are presented.
- There are $4 \div 6$ showers not associated with charged particles in the γ-calorimeter.
- The total energy of the final state is in the range $34.5 < E_{tot} < 38\ GeV$.

A major part of the events with such a topology originates from diffractively produced $\pi^+\pi^-\pi^-\pi^0\pi^0$ system. To select the reaction (1) from such a background the events with the only one $\gamma\gamma$ pair having effective mass within the range 110 MeV $\leq M_{\gamma\gamma} \leq$ 170 MeV (corresponding to the π^0 mass and apparatus resolution) were chosen.

Two folded mass spectrum of $\pi^+\pi^-(\gamma\gamma)$ system where $(\gamma\gamma)$ pair effective mass is in the π^0 region has a peak at M_η with $\sigma_M = 6.3$ MeV , after imposing 1C constrain $M_{\gamma\gamma} = M_{\pi^0}$. When events from this peak are taken , the second η meson signal in the remaining $\gamma\gamma$ system is strongly enhanced.

Events lying inside the ellipse centered at (M_η, M_η) in the $M_{3\pi}, M_{\gamma\gamma}$ plane and with half-axis lengths of 15 MeV and 70 MeV respectively were chosen for the analysis. Biplot of these two invariant masses in the η mesons region is shown in the fig. 1a. The background can be estimated as a number of events in the outer ellipse of the equal square. Its level in such a case is no more than 20%. Combinatorial ambiguous events which can't be uniquely decomposed as $\eta\eta\pi$ were excluded from the analysis. To the remaining events 1C ($M_{\gamma\gamma} = M_\eta$) and 2C ($M_{\gamma\gamma} = M_{\pi^0}, M_{3\pi} = M_\eta$) procedures were applied.

Fig. 1b gives $|t'|$ distribution. In the region $|t'| \leq 0.40\ GeV^2$ it is well fitted with the sum of two exponents having slopes: $b_1 = 55.0 \pm 4.\ GeV^{-2}$ ($\approx 40\%$ of the events) and $b_2 = 6.8 \pm 0.8\ GeV^{-2}$. This shows the significant contribution of the coherent diffraction process on nuclei. The cut $|t'| \leq 0.15\ GeV^2$ was applied to select diffractive production of the studied system.

The $\eta\eta\pi^-$ and $\eta\eta$ systems effective mass spectra are presented at the fig.2(a),(b). Two peaks at $1.7 \div 1.9$ GeV and near 1.45 GeV are clearly visible as it was seen earlier [1]. In the $\eta\pi^-$ mass spectrum (fig.3a) there are $a_0(980)$-meson peak and a weak signal of $a_2(1320)$.

3. Partial wave analysis of the $\eta\eta\pi^-$ system.

To perform PWA of the system a modified version of the Illinois' PWA program for 3 pseudo-scalar particles using the isobar model [7] have been used. The parameters of the model are presented by complex density matrix elements in the basis of $J^P L M \eta X$ states where J^P – is spin-parity, L – orbital angular momentum between an isobar and the meson in the decay mode X, M – projection number onto Z axis of Gottfried-Jackson frame, η – naturality.

The parameters were fitted with the event-by-event maximum likelihood method in 60 MeV-width bins of the 3-particles mass in $1.5 \div 2.5$ GeV range.

The acceptance of the setup and the cuts applied were taken into account numerically by processing of generated events through the setup model. The events were generated uniformly on the PWA variables and according to the experimental $|t'|$-distribution.

All the calculations were done using $\eta = +1$ waves assuming a pomeron exchange to be dominant. Only $M = 0$ value was accepted due to the uniformity of the Treiman-Yang angle distribution (see fig.3(d)).

All the introduced isobars were parameterized by the relativistic Breit-Wigner formula with corresponding spin barrier factors. The masses and widths of isobars were varied

within the limit of ± 20 MeV for the masses and $\pm 30\%$ for the widths. For the a_0-meson Flatte [8] parameterization was also tried with wide variations of parameters. The main results given below are almost independent from the choice of parameterization.

All the possible states up to spin $J = 3$ decaying through the isobars with $L = (S, P, D, F)$ have been included. There was also a pseudo-wave "FLAT" uniformly distributed throughout the phase space.

Different states with the same J^P supposed to be coherent as it turned out that in our case such a parameterization of ρ-matrix doesn't affect significantly both the waves behaviour and the likelihood value, while the number of fitting parameters decreases and the fit stability improves. The following waves turned out to be significant :

FLAT	
$\mathbf{0^-}$	$S(a_0\eta)$; $S(f_0\pi)$
$\mathbf{2^-}$	$D(a_0\eta)$; $S(a_2\eta)$

Note that the waves with high (> 2) spin and L are absent in this set. States with $J^P = 1^+$ are also absent in the minimal set above . When they were tried to be included they had low statistical significance, were incoherent with other waves and only slightly affected on the major waves intensities and phases.

The $FLAT$ intensity is smooth in the whole mass range, it doesn't exhibit any structures and incorporates about 25 % of events what coincides with the 20 % background estimation.

The quality of the description of experimental data by the obtained solution (see below) is demonstrated with two-particle mass spectra for real and Monte-Carlo events shown at the fig.3(a), (b). The differences between them might be explained by background not described by the set of included waves as well as by incoherent background under η meson peak which cannot be described by "FLAT".

In the mass range up to $M \approx 2$ GeV the state $0^- S(a_0\eta)$ dominates and has maximum at $1.8 \div 1.9$ GeV (fig.4(a)). Its phase with respect to slowly varying $2^- D(a_0\eta)$ wave (fig.4(c)) exhibits the fast increase in this range by $\approx 80^o$ (fig.5). Such a behaviour depends slightly upon the isobars parameterization.

The amplitude squared of this wave is well described by Breit-Wigner function with barrier factor in the Quigg-Hippel form [9] with fixed $R_0 = 1.0$ fm and parameters

$$M = 1840 \pm 10(\text{stat.}) \pm 10(\text{syst.}) \text{ MeV}, \quad \Gamma = 210 \pm 30(\text{stat.}) \pm 30(\text{syst.}) \text{ MeV}. \qquad (2)$$

(see solid curve on the fig.4(a)). Systematic errors correspond to the variations of values for different background parameterization.

The curve superimposed on the histogram at fig.5 presents the resonance phase motion in this parameterization.

The resemblance of the obtained parameters to those of 0^{-+} resonance observed earlier in the $\pi^+\pi^-\pi^-$ and $K^+K^-\pi^-$ modes [10,11], makes us to assume that this is the same object $\pi(1800)$.

The narrow structure in the $\eta\eta$ channel at ≈ 1.5 GeV was parameterized as $J^P = 0^+$ resonance. Designated as $f_0(1460)$ it yields significant contribution only in the state $0^- S(f_0\pi^-)$ (fig.4(b)) which has also maximum in the $1.8 \div 1.9$ GeV region.

The phase of this wave is compatible with a constant with respect to $0^- S(a_0\eta)$. This allows us to suppose that two observed states with $J^P = 0^-$ are different decay channels of the same resonance. Under this assumption the branching ratio is

$$\frac{BR(\pi^-(1800) \to f_0^{(\eta\eta)}(1460)\pi^-)}{BR(\pi^-(1800) \to a_0^{(\pi^-\eta)}\eta)} = 0.08 \pm 0.03 \tag{3}$$

The most likely $f_0(1460)$ parameters are

$$M = 1460 \pm 20 \text{ Mev}, \quad \Gamma = 100 \pm 30 \text{ Mev}. \tag{4}$$

The fit with $J^P = 2^+$ quantum numbers for the narrow resonance in the $\eta\eta$ channel lead to a sufficient drop in the maximized functional. In this case neither the peak in the $\eta\eta$ spectrum was described nor any wave through f_2 included in the wave set instead of $0^- S(f_0\pi^-)$ exhibits a significant structure. When 2^+ isobar is introduced simultaneously with the waves through $f_0(1460)$, the intensities of waves through $f_2(1460)$ are consistent with zero within statistical errors .

A scalar meson in the $\eta\eta$ system in this mass region was observed for the first time in [12,13]. The $f_0(1460)$ in the reaction (1) was reported in [1]. Similar structures in the $\eta\eta$ channel at masses 1.47–1.52 GeV were observed in $p\bar{p}$-annihilation [2,3,4,5].

Because of the proximity of the main parameters in the following discussion we don't make a distinction between $f_0(1460)$ and $f_0(1590)$ and identify them as $f_0(1520)$.

In our preceeding paper [14] a peak was observed in the $\eta\eta'\pi^-$ system near its threshold which is probably due to the same resonance $\pi(1800)$. A branching ratio was determined for two channels :

$$\frac{Br(\pi(1800) \to \eta\eta'\pi^-)}{Br(\pi(1800) \to \eta\eta\pi^-)} = 0.29 \pm 0.07$$

Assuming of the dominance of $\pi(1800) \to f_0(1520)\pi$ channel in the $\pi(1800) \to \eta\eta'\pi$ decay as it is the only one allowed quasi-two-body decay and using (3), one obtains the branching ratio

$$\frac{Br(\pi(1800) \to f_0(1520)\pi^- \to \eta\eta'\pi^-)}{Br(\pi(1800) \to f_0(1520)\pi^- \to \eta\eta\pi^-)} = 3.6 \pm 2.$$

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It is consistent with a similar ratio for $f_0(1590)$ [15] and points to the hybrid $q\bar{q}g$ meson features of the $\pi(1800)$ [16].

The branching ratio for $\pi(1800)$ decaying into $\pi^+\pi^-\pi^-$ and $\eta\eta\pi^-$ (including both states observed) channels is

$$\frac{Br(\pi(1800) \to \eta\eta\pi^-)}{Br(\pi(1800) \to \pi^+\pi^-\pi^-)} = 0.5 \pm 0.1 \tag{5}$$

There are broad maxima at ≈ 1.8 GeV and ≈ 2.2 GeV in the waves $2^- S(a_2\eta)$ (fig.4d) and $2^- D(a_0\eta)$. Such behaviour can be attributed to the $J^{PC} = 2^{-+}$ resonances with

masses $M \approx 1.7$ GeV and $M \approx 2.1$ GeV, which were observed in the $f_2\pi^-$, $\epsilon\pi^-$ and $\rho^0\pi^-$ channels [11,17].

A nonuniformity of the Gottfried-Jackson angle experimental distribution of π^--meson, namely its rise up at $|\cos\theta_{GJ}| > 0.8$, led us to the conclusion on the preference of non-zero spin of the dominant state in our previous work [1]. In the present PWA solution this rise is mainly due to the contribution of wave $J^{PC} = 2^{-+}$.

4. Conclusions

The PWA results show that the peak in the $\eta\eta\pi^-$ mass spectrum in the reaction (1) is due to diffractive production of an object with $J^{PC} = 0^{-+}$ quantum numbers decaying via $a_0^-(980)\eta$ channel. Its Breit-Wigner parameters are

$$M = 1840 \pm 10(\text{stat.}) \pm 10(\text{syst.}) \text{ MeV}, \quad \Gamma = 210 \pm 30(\text{stat.}) \pm 30(\text{syst.}) \text{ MeV}.$$

The narrow peak observed in the $\eta\eta$ mass spectrum is well described by introducing a resonance having $J^{PC} = 0^{++}$ and parameters

$$M = 1460 \pm 20\text{MeV}, \quad \Gamma = 100 \pm 30\text{MeV},$$

and can't be described with alternative state $J^{PC} = 2^{++}$.

The relative width of decay into two channels is:

$$\frac{BR(\pi^-(1800) \to f_0^{(\eta\eta)}(1460)\pi^-)}{BR(\pi^-(1800) \to a_0^{(\pi^-\eta)}\eta)} = 0.08 \pm 0.03$$

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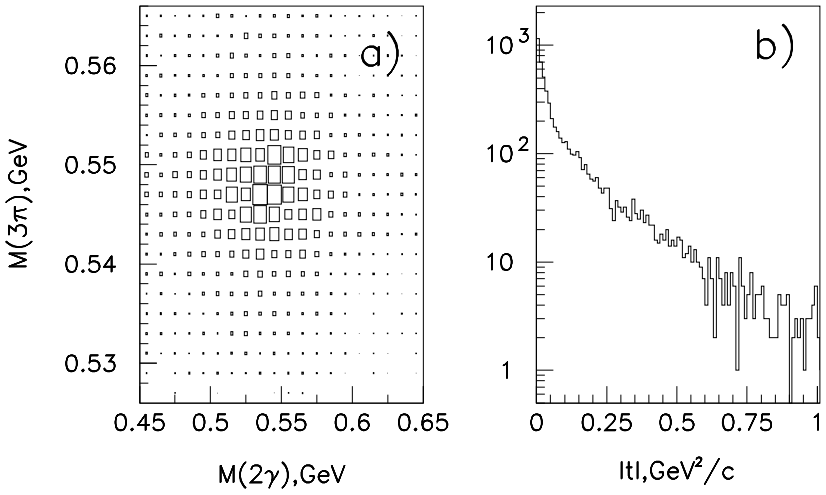

Fig. 1. (a) $M(\gamma\gamma)$, $M(\pi^+\pi^-\pi^0)$ biplot in the η mesons mass region; (b) $|t'|$ distribution for the $\eta\eta\pi^-$ events.

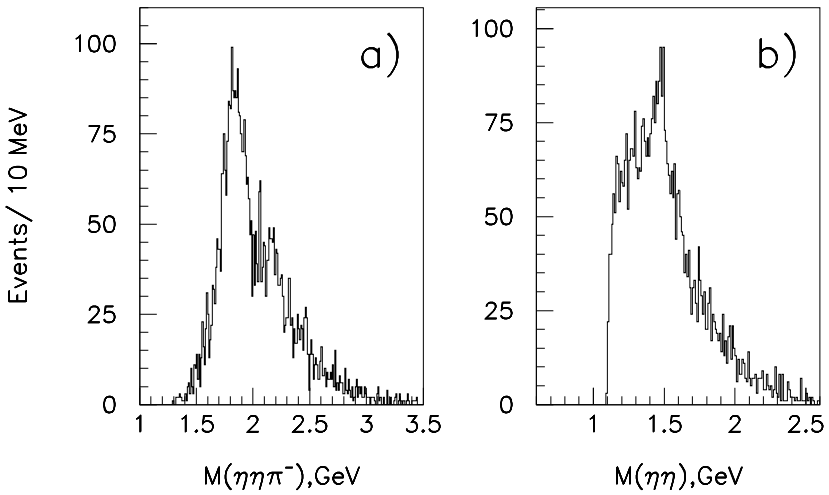

Fig. 2. (a) $\eta\eta\pi^-$ mass spectrum ; (b) $\eta\eta$ mass spectrum

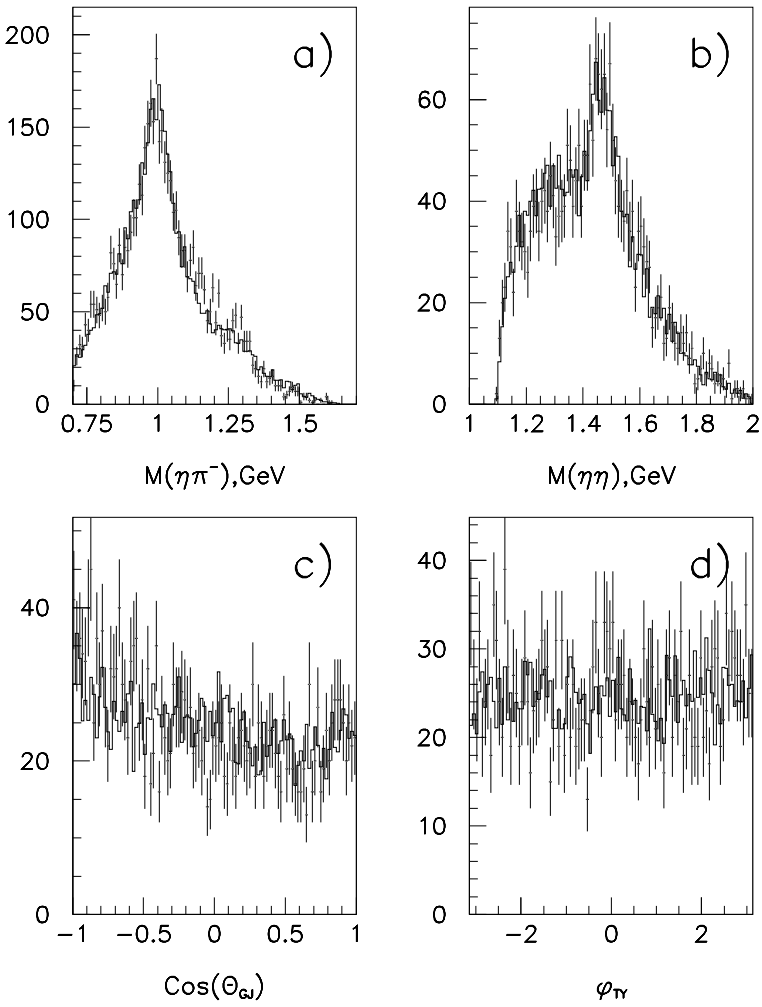

Fig. 3. Experimental (points with errors) and generated in accordance with the PWA decision (solid curves) distributions on the PWA variables : (a) $M(\eta\pi^-)$, (b) $M(\eta\eta)$, (c) $\cos\theta_{GJ}$, (d) ϕ_{TY}.

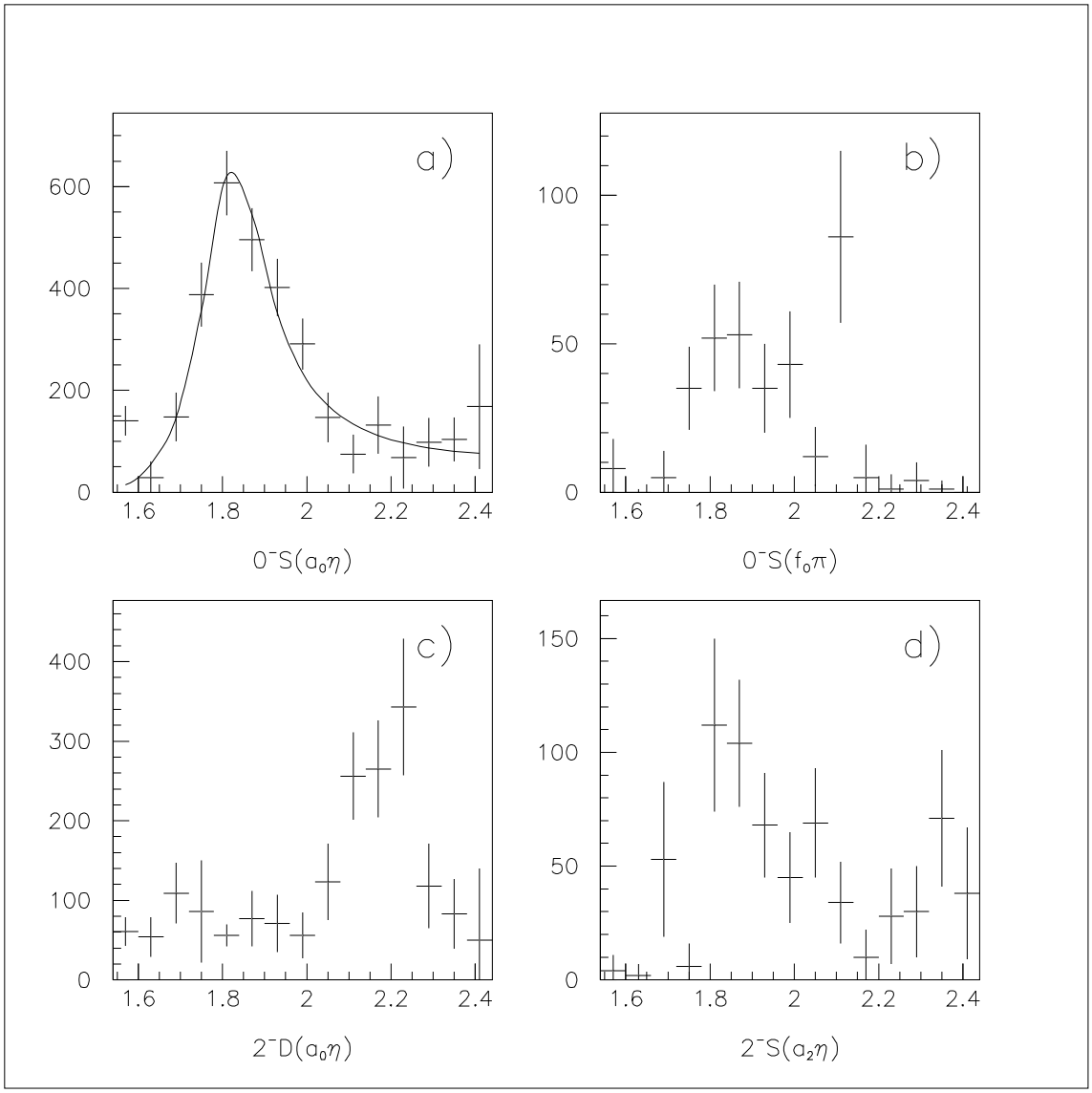

Fig. 4. PWA waves intensities.

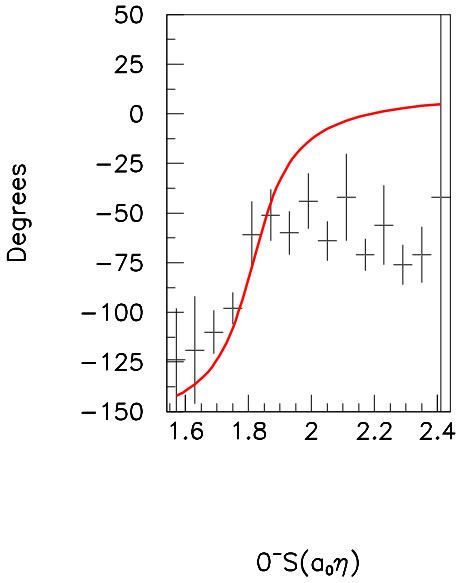

Fig. 5. $0^- S(a_0\eta)$ wave phase with respect to that of $2^- D(a_0\eta)$.