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D.V. Amelin, E.B. Berdnikov, S.I. Bityukov, G.V. Borisov, Yu.P. Gouz, V.A. Dorofeev, R.I. Dzhelyadin, A.V. Ekimov, Yu.M. Ivanyushenkov, I.A. Kachaev, A.N. Karyukhin, Yu.A. Khokhlov, G.A. Klyuchnikov, V.F. Konstantinov, S.V. Kopikov, M.E. Kostrikov, V.V. Kostyukhin, A.A. Kriushin, V.D. Matveev, A.P. Ostankov, D.I. Ryabchikov, O.V. Solovianov, E.A. Starchenko, N.K. Vishnevsky, E.V. Vlasov, A.M. Zaitsev

IHEP, Protvino

T.A. Lomtadze, E.G. Tskhadadze

IPh, Tbilisi

STUDY OF DIFFRACTIVE REACTION $\pi^- A \to \eta\eta\pi^- A$ AT THE MOMENTUM P_{π^-}=37 GeV/c

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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. 9, 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 the beryllium 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 a resonant behaviour with parameters $M = 1840 \pm 10$(stat.)± 10(syst.) MeV, $\Gamma = 210 \pm 30$(stat.)± 30(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.

Аннотация

Амелин Д.В. и др. Изучение дифракционной реакции $\pi^- A \to \eta\eta\pi^- A$ при импульсе P_{π^-}=37 ГэВ/с: Препринт ИФВЭ 95-112. – Протвино, 1995. – 9 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_{π^-}=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 $a_o^-(980)\eta$, имеющая резонансное поведение с параметрами $M = 1840 \pm 10$(стат.) $\pm$ 10(сист.) МэВ, $\Gamma = 210 \pm 30$(стат.) $\pm$ 30(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.

Introduction

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

$$\pi^- A \rightarrow \eta\eta\pi^- A. \quad (1)$$

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

Some results on reaction (1) with smaller statistics have been already reported [1]. A resonance-like peak was observed at $M \approx 1.8$ GeV in the effective mass spectrum of the $\pi^-\eta\eta$ 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].

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

Events selection

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

One of the η-mesons of 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:

- 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.

The bulk of the events with such a topology originate from diffractively produced $\pi^+\pi^-\pi^-\pi^0\pi^0$ system. To select reaction (1) from such a background the events with 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 has an effective mass in the π^0 region, after 1C fit ($M_{\gamma\gamma} = M_{\pi^o}$), has a peak at M_η with $\sigma_M = 6.3$ MeV. When $\eta \to \pi^+\pi^-\pi^o$ is imposed, 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 and 70 MeV respectively were chosen for the analysis. The biplot of these two invariant masses in the η mesons region is shown in 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 not more than 20%. Combinatorial ambiguous events which can't be uniquely decomposed as $\eta\eta\pi$ were excluded from the analysis. The 1C ($M_{\gamma\gamma} = M_\eta$) and 2C ($M_{\gamma\gamma} = M_{\pi^0}, M_{3\pi} = M_\eta$) procedures were applied to the remaining events.

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

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

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 [7] have been used. The parameters of the model are presented by complex density matrix elements on the basis of $J^PLM\eta X$ 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 the 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 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 made using $\eta = +1$ waves under assumption of a pomeron exchange to be dominant. Only $M = 0$ value was accepted due to the uniformity of the Treiman-Yang angle distribution (Fig.3d).

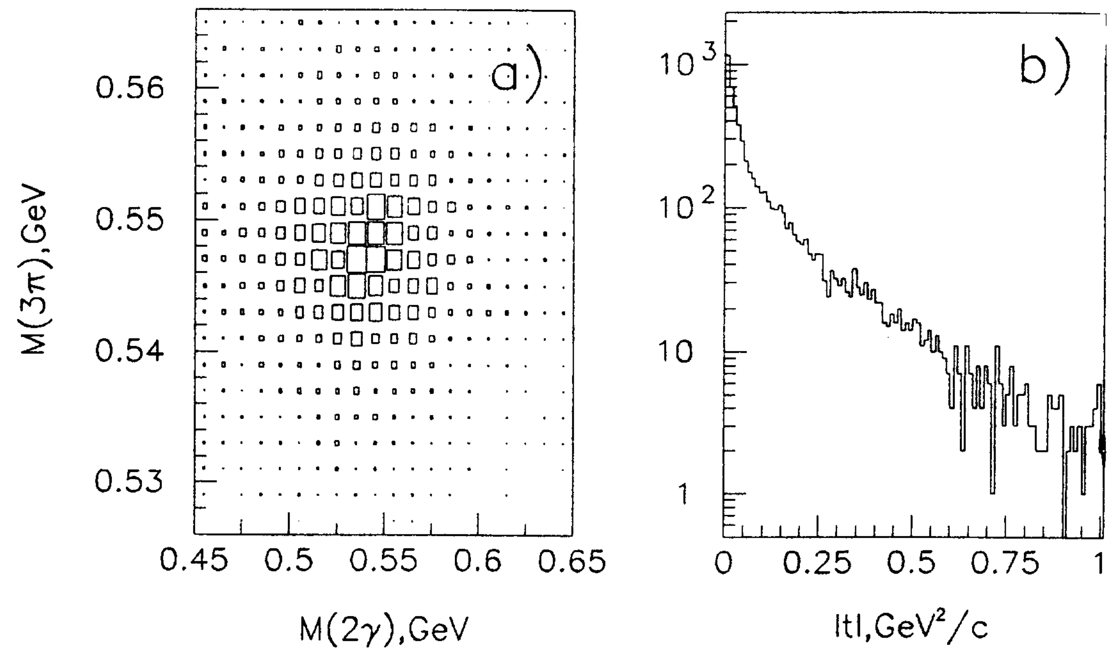


Fig. 1. a) $M(\gamma\gamma)$, $M(\pi^+\pi^-\pi^0)$ biplot in the η mesons mass region; b) $|t'|$ distribution for the $\eta\eta\pi^-$ events.

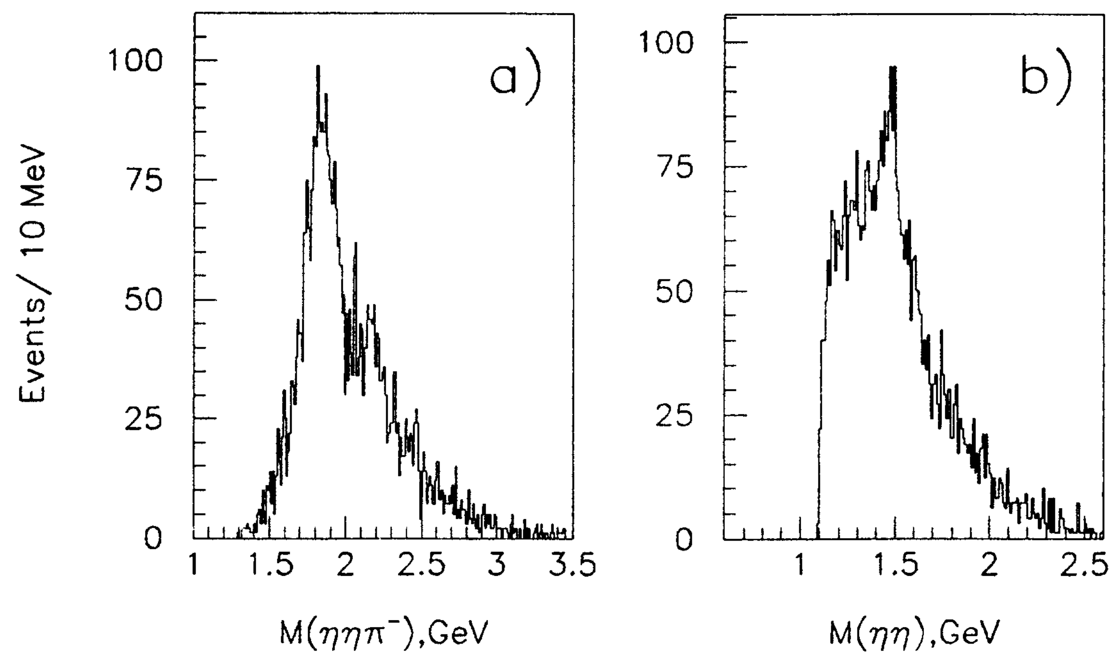


Fig. 2. a) $\eta\eta\pi^-$ mass spectrum; b) $\eta\eta$ mass spectrum.

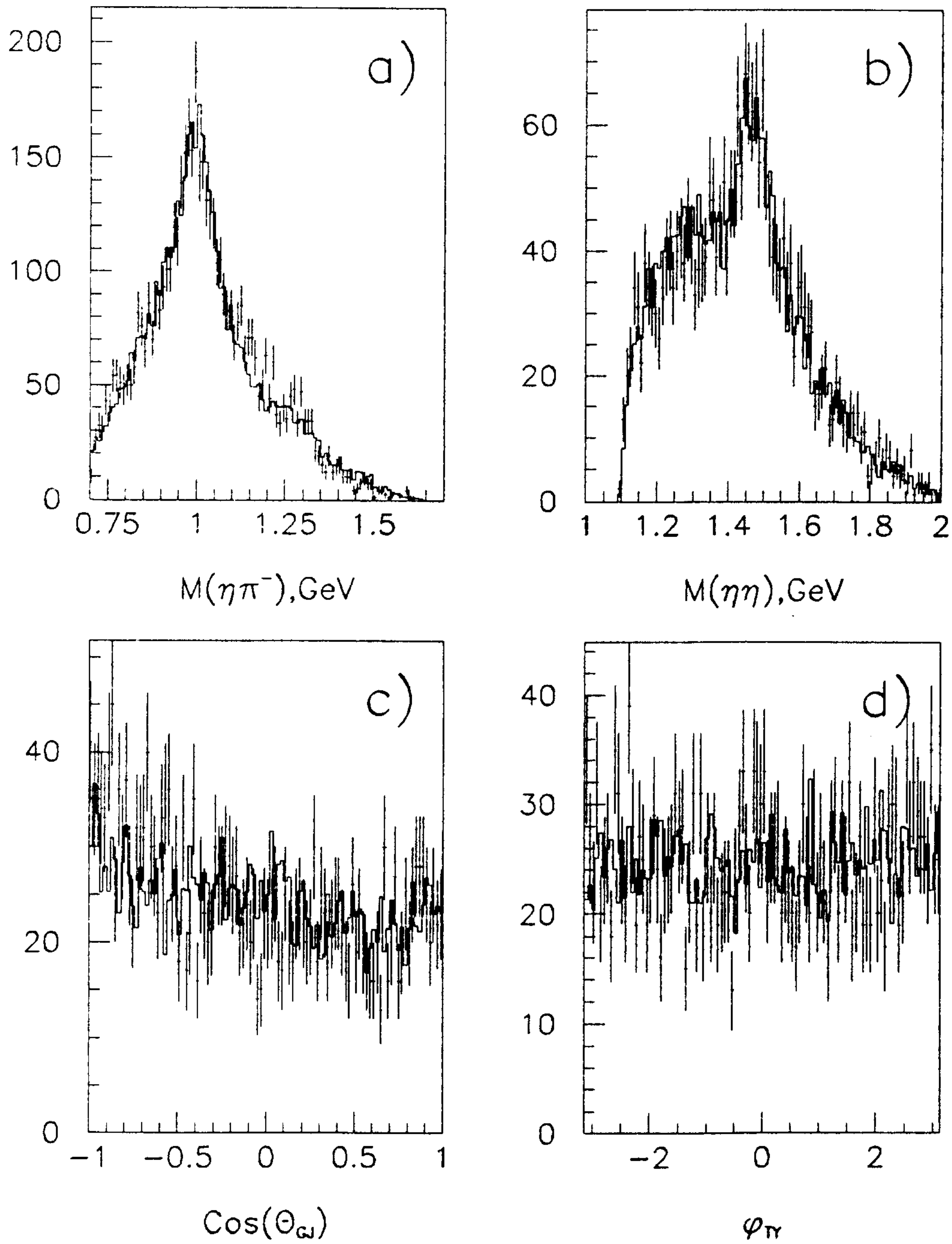


Fig. 3. Experimental (points with errors) and generated in accordance with the PWA decision (solid curves) distributions on the PWA variables: a) $M(\eta\pi^-)$; b) $M(\eta\eta)$; c) $\cos\theta_{GJ}$; d) ϕ_{TY}.

All the introduced isobars were parameterized by the relativistic Breit-Wigner formula with the 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 the Flatte parameterization [8] with wide variations of parameters was also tried. 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 are supposed to be coherent as, in our case, such parameterization of ρ-matrix turned out not be 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

0^- $S(a_0\eta)$; $S(f_0\pi)$

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 we tried to include them, they turned out to be of low statistical significance, being incoherent with other waves and only slightly affected 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, which agrees with the 20% background estimation.

The quality of the experimental data description with the obtained solution (see below) is demonstrated with distributions for real and Monte-Carlo events shown in Fig.3. The differences between them may 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 the maximum at $1.8 \div 1.9$ GeV (Fig.4a). Its phase with respect to slowly varying $2^-D(a_0\eta)$ wave (Fig.4c) exhibits the fast increase by $\approx 80^o$ in this range (Fig.5). Such a behaviour slightly depends upon the isobars parameterization.

The wave amplitude squared is well described by Breit-Wigner function with a 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.4a). The systematic errors correspond to the variations of values for different background parameterizations.

The curve superimposed on the histogram in 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 this to be the same object $\pi(1800)$.

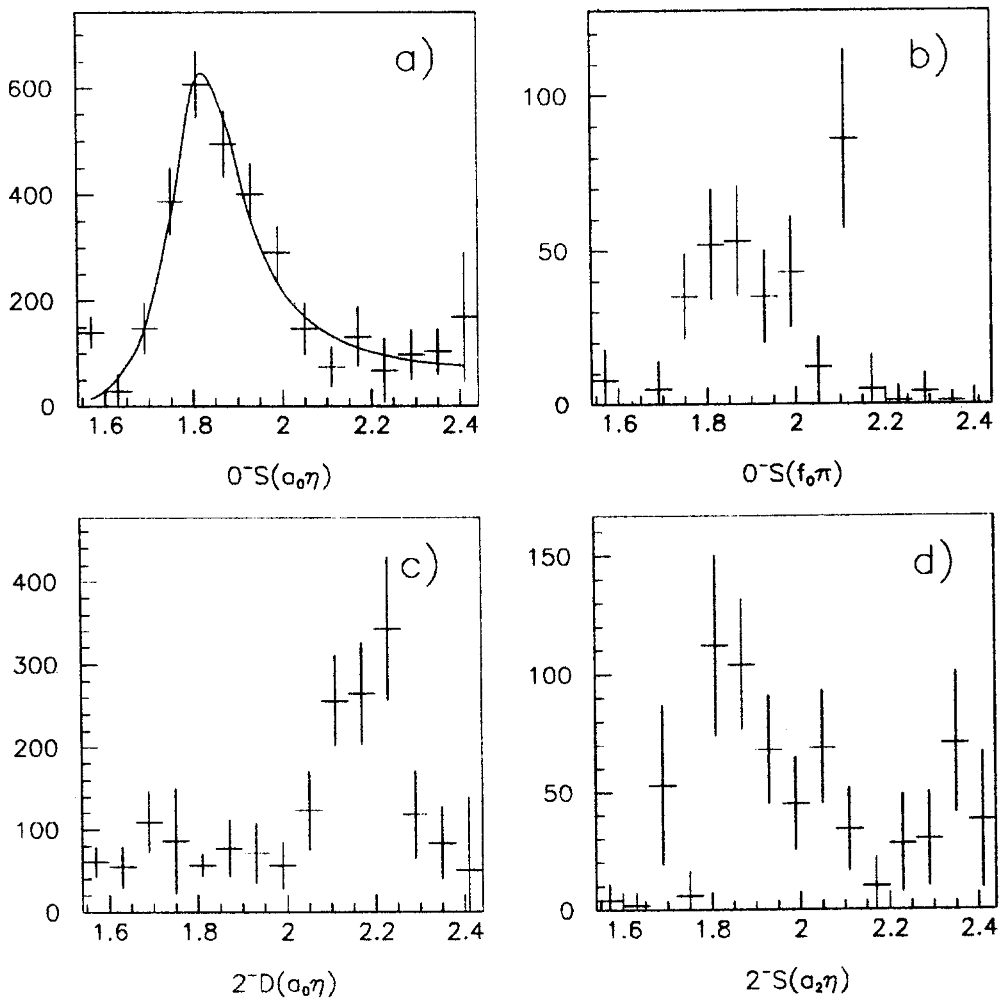
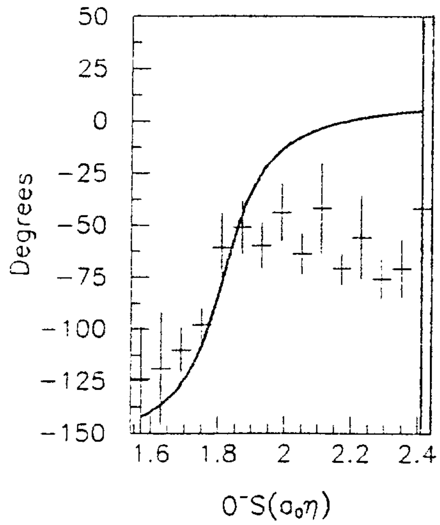


Fig. 4. PWA waves intensities.

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



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 a significant contribution only in the state $0^- S(f_0\pi^-)$ (Fig.4b) which also has a maximum in the $1.8 \div 1.9$ GeV region.

The phase of this object is compatible with a constant with respect to $0^- S(a_0\eta)$. It allows us to suppose that the 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 leads to much worse likelihood and does not describe experimental data. When 2^+ isobar is introduced simultaneously with $f_0(1460)$, the intensities of all waves $f_2(1460)\pi$ 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 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 presented below we do not distinguish 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 the dominance of $\pi(1800) \to f_0(1520)\pi$ channel in the $\pi(1800) \to \eta\eta'\pi$ decay to be the only on allowed quasi-two-body decay and using (3) one obtains the branching ratio

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

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

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

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 at $|\cos\theta_{GJ}| > 0.8$, led us in [1] to the conclusion on the preference of non-zero spin of the dominant state. In the present PWA solution this rise is mainly due to the contribution of wave $J^{PC} = 2^{-+}$.

Conclusions

The PWA results show that the peak in the $\eta\eta\pi^-$ mass spectrum in reaction (1) is due to the 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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References

[1] Bityukov S.I. et al. Phys. Lett. **B268** (1991) 137.

[2] Amsler C. et al. Nucl. Phys. **A558** (1993) 3C.

[3] Armstrong T.A. et al. Phys. Lett. **B307** (1993) 394.

[4] Anisovich V.V. et al. Phys. Lett. **B323** (1994) 233.

[5] Anisovich V.V. et al. Phys. Rev. **50** (1994) 1972.

[6] Beladidze G.M. et al. Z.Phys. **C54** (1992) 235.

[7] Hansen J.D. et al. Nucl. Phys. **B81** (1974) 403.

[8] Flatté S.M. Phys. Lett. **B63** (1976) 224.

[9] G. Quigg, F. von Hippel. Experimental Meson Spectroscopy, ed. C. Baltay and A. H. Rosenfeld, Columbia University Press, 1970, p.477.

[10] Berdnikov E.B. et al. Phys. Lett. **B337** (1994) 219.

[11] Berdnikov E.B. et al. Proceedings of the Second Biennial Workshop on Nucleon-Antinucleon Physics, ITEP, Moscow, September 13-18, 1993.

[12] Binon F.G. et.al. Nuov. Cim. **78A** (1983) 313.

[13] Alde D. et.al. Nucl. Phys. **B269** (1986) 485.

[14] Beladidze G.M. et al. Sov.J.Nucl.Phys. **55** (1992) 1535.

[15] Binon F.G. et.al. Nuov. Cim. **80A** (1984) 363.

[16] Borisov G.V., Gershtein S.S. and Zaitsev A.M. Sov.J.Nucl.Phys. **55** (1992) 1441.

[17] Daum C. et al. Phys. Lett. **B89** (1980) 285.

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ГНЦ РФ Институт физики высоких энергий
142284, Протвино Московской обл.

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