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STUDY OF RESONANCE PRODUCTION IN DIFFRACTIVE REACTION $\pi^- A \to \pi^+\pi^-\pi^- A$

(VES collaboration)

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Abstract

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The results on partial wave analysis of diffractive reaction $\pi^- A \to \pi^+\pi^-\pi^- A$ at the momentum 36 GeV/c at the scintillator target are presented. The resonance at $m = 1.8$ GeV with $J^{PC} = 0^{-+}$ ($\pi(1800)$) is clearly seen in this reaction. The characteristics of $\pi(1800)$ point to possible exotic nature of this object.

Аннотация

Амелин Д.В. и др. Изучение образования резонансов в диффракционной реакции $\pi^- A \to \pi^+\pi^-\pi^- A$: Препринт ИФВЭ 95-78. – Протвино, 1995. – 8 с., 4 рис., библиогр.: 16.

Представлены результаты парциально-волнового анализа реакции $\pi^- A \to \pi^+\pi^-\pi^- A$ на мишени из сцинтиллятора при импульсе пучка 36 GeV/c. Резонанс с массой $m = 1.8$ GeV и $J^{PC} = 0^{-+}$ ($\pi(1800)$) ясно виден в этой реакции. Характеристики $\pi(1800)$ указывают на возможную экзотическую природу этого объекта.

Introduction

The VErtex Spectrometer (VES) setup is a large aperture magnetic spectrometer including the system of proportional and drift chambers, a multichannel threshold Čerenkov counter, lead-glass γ-detector and plastic scintillator target. The setup runs with the negative particle beam with the momentum of 36.6 GeV/c. The description of the setup can be found in [1].

In this paper we present the results on the reaction

$$\pi^- A \quad \rightarrow \quad \pi^+\pi^-\pi^- A \tag{1}$$

at small momentum transfer $|t'| < 0.06\ GeV^2$

1. Selection criteria

To select diffractive dissociation process (1) the following criteria were applied:

1) the event has one positive and two negative pions in the final state and no gammas;

2) the summary energy of the charged particles lies in the region of the "elastic peak": $34.5 < E_{tot} < 37.5$ GeV;

3) the momentum transfer squared is $|t'| < 0.06$ GeV^2. Under this t' cut diffractive reactions on carbon dominate in the data (see Fig.1b).

The results under discussion are based upon the statistics of about $2 \cdot 10^6$ events. Our preliminary results were published in [2,4].

2. The Partial wave analysis

The PWA of the system $\pi^+\pi^-\pi^-$ has been performed in the 0.7–2.6 GeV mass region in 20 MeV bins. The upgraded version of the Illinois PWA program [7] has been used for the analysis. The set of partial waves included into the analysis is given below:

FLAT					
0⁻	$0^-S0+\ \epsilon$	$0^-D0+\ f_2$			
	$0^-S0+\ f_0$				
	$0^-P0+\ \rho$				
1^+	$1^+S0+\ \rho$	$1^+D0+\ \rho$	$1^+P0+\ f_2$		
	$1^+P0+\ \epsilon$				
	$1^+P0+\ f_0$				
	$1^+S1+\ \rho$				
1^-	$1^-P1+\ \rho$				
2^-	$2^-S0+\ f_2$	$2^-P0+\ \rho$	$2^-D0+\ \epsilon$	$2^-D0+\ f_0$	$2^-D0+\ f_2$
	$2^-S1+\ f_2$	$2^-P1+\ \rho$			
2^+	$2^+D1+\ \rho$				
3^+	$3^+S0+\ \rho_3$	$3^+P0+\ f_2$	$3^+D0+\ \rho$		
4^-	$4^-P0+\ \rho_3$	$4^-D0+\ f_2$	$4^-F0+\ \rho$		

The notations of the waves are given here in the form of $J^P LM\eta$ *isobar* [7]. The FLAT wave is constant over all variables and non-interfering with other waves. Each line contains states which are assumed to be coherent in order to decrease the number of parameters in the ρ-matrix. For the channel under study with $J^{PC}=0^{-+}$ all the main waves $0^-S0+\ \epsilon$, $0^-S0+\ f_0$, $0^-P0+\ \rho$ are assigned to their own density matrix elements and are allowed to interfere with each other.

The isobars $\rho(770)$, $f_2(1270)$, $\rho_3(1690)$ have been described by relativistic Breit-Wigner functions with the standard parameters from PDG [5]. The S-wave in the channel $\pi^+\pi^-$ has been parameterized by two different states:

f_0 — the "narrow" resonance with the $f_0(975)$ parameters;
ϵ — the "broad" wave which is the AMP M-solution [6] with $f_0(975)$ removed[1].

The presentation in the form of two independent states allows us to describe the experimental behaviour of the S-wave.

3. Results of PWA

We present below main features of the most significant waves. At the end of this section we will return to the $J^{PC}=0^{-+}$ wave and discuss its behavior in more detail.

The effective mass distribution of experimental events (acceptance corrected) is shown in Fig.1a. The t' distribution is presented in Fig.1b. The Deck model predictions [8] are shown in Fig.1c. The FLAT wave is not shown, it is negligible and has no structures, which indicates the good quality of the fit. Main waves are shown in Fig.2,3,4.

[1] We have named it ϵ instead of f_0 because it includes broad part of $\pi\pi$ amplitude and does not coincide with any specific f_0 resonance.

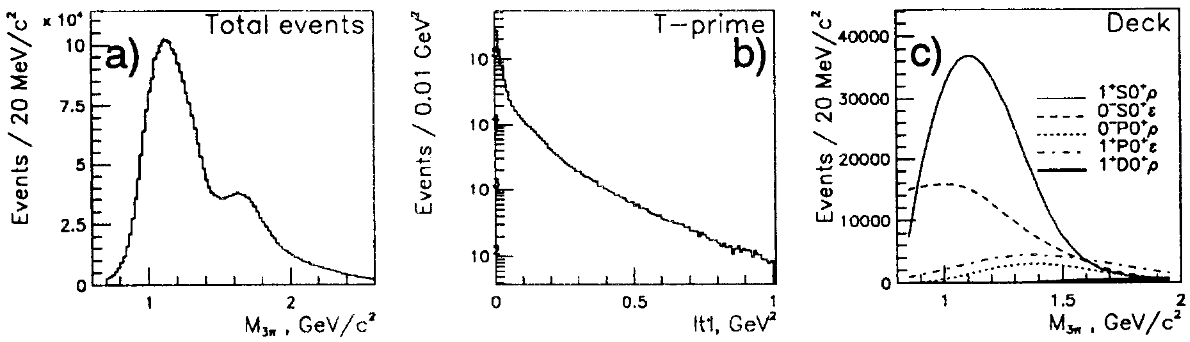

Fig. 1. Effective mass distribution, acceptance corrected (a); t' distribution (b); Deck model predictions for some waves (c).

$J^{PC} = 0^{-+}$. In the wave $0^- S$ $\epsilon\pi$ one can see a broad maximum around $M \approx 1.3$ GeV, which is often interpreted as $\pi(1300)$ resonance, and a distinct resonance-like peak in the waves $\epsilon\pi$ and $f_0\pi$ at $M \approx 1.8$ GeV (see Fig.4).

$J^{PC} = 1^{++}$. A set of the largest $J^{PC} = 1^{++}$ waves is presented in Fig.2. In the wave $1^+S0 + \rho$ the a_1 signal is seen at $M \approx 1.2$ GeV together with some shoulder at $M \approx 1.7$ GeV. Extraction of the a_1 parameters in this wave is model dependent due to the significant Deck-type background, peaking in the same mass region. In Fig.1c the Deck effect contribution to this wave, calculated according to the Ascoli model [8], is shown. In the wave $1^+P0{+}\epsilon$ there are some indications of the structures at $M \approx 1.1$ GeV and $M \approx 1.7$ GeV. In the wave $1^+D0{+}$ ρ a clear bump is seen with the mass about 1.7 GeV. Its value significantly exceeds the expected contribution from the Deck effect. In the region $0.8 - 1.3$ GeV this wave is badly measurable due to the huge signal in the $1^+S0 +$ ρ wave and its shape depends on the $\rho(770)$ parameterization. So we don't consider the structures in this region as significant. Significant excess of the $1^+S0 + \rho$ wave over the Deck effect together with the structures in $1^+P0 + \epsilon$, $1^+D0 + \rho$ waves can be considered as an indication of an object with $J^{PC} = 1^{++}$, $M \approx 1.7$ GeV, which decays into all those channels with comparable probability. A similar signal in the 1^{++} wave was observed in $f_1(1285)\pi$ channel [14].

$J^{PC} = 2^{-+}$. Waves with $J^{PC} = 2^{-+}$ are shown in Fig.3. In the wave $2^-S0 + f_2$ a clear signal is seen from $\pi_2(1670)$ resonance. In the wave $2^-P0 + \rho$ an enhancement in the π_2 region and a broad maximum around $M \approx 1.2$ GeV are observed. This wave around the maximum has a small coherence factor with the diffractive waves and large systematic errors. In the $2^-D0 + \epsilon$ wave one can observe the structure with two maxima at $M \approx 1.7$ GeV and $M \approx 2.1$ GeV. The former can be identified as $\pi_2(1670)$ while the latter is probably a new object. The first indications of its existence were presented earlier in [9]. In the wave $2^-D0 + f_2$ one can see a signal with the maximum about $M \approx 1.8$ GeV. This signal has a non-Breit-Wigner shape and phase motion, and the reason of its appearance can be an interference of two

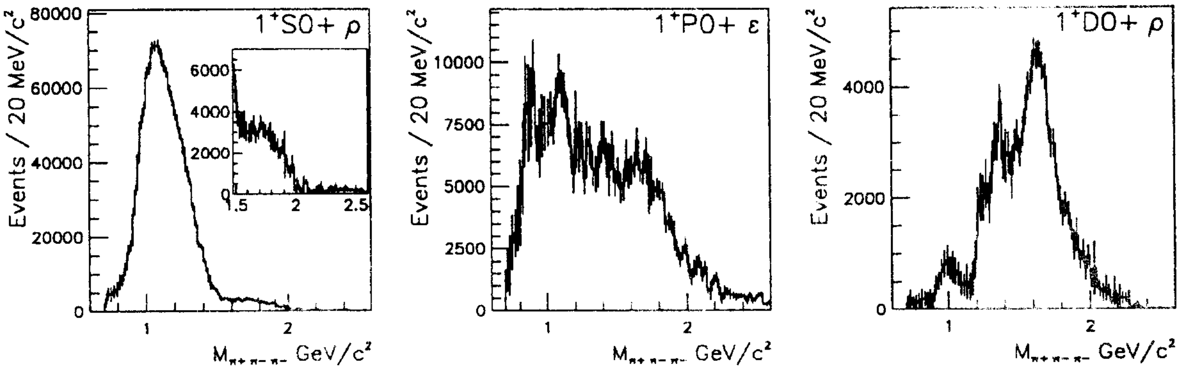

Fig. 2. Main $J^{PC} = 1^{++}$ waves.

objects seen in $2^- D0 + \epsilon$. The wave $2^- D0 + f_0(974)$ is by an order of magnitude smaller than the wave $2^- D0 + \epsilon$, that is in accordance with the expectations for the decays of isovector $q\bar{q}$ mesons. Parameters of these objects were determined by *K-matrix* formalism [15,9]. Two poles, Deck background and polynomial background were included in the model. Parameters of *K-matrix* poles are

$$\pi_2: \quad M = 1.73 \pm 0.02 \text{ GeV}, \quad \Gamma = 310 \pm 20 \text{ MeV};$$
$$\pi_2': \quad M = 2.09 \pm 0.03 \text{ GeV}, \quad \Gamma = 520 \pm 100 \text{ MeV}.$$

The errors include both systematic and statistical ones. These values are consistent with the results of the previous work [9].

$J^{PC} = 2^{++}$. The wave $2^+ D1 + \rho$ is also shown in Fig.3. It is the largest wave with nonzero spin projection $M = 1$. This wave is dominated by $a_2(1320)$ meson. Note that in the low t region the production of a_2 is suppressed. Nevertheless this signal is clearly seen and has a Breit-Wigner shape and phase motion. This is a good indication of the correctness of PWA.

Let's return now to the detailed study of the $J^{PC} = 0^{-+}$ states. Fig.4 shows the wave with $J^{PC} = 0^{-+}$ in channels $\epsilon\pi^-$, $f_0\pi^-$, $\rho\pi^-$, $f_2\pi^-$. The behavior of the $0^- S0 + \epsilon$ wave at low $M_{3\pi}$ significantly differs from the Deck model predictions. The large Deck effect and broadness of the signal prevents us from extracting the parameters of (hypothetical) pseudoscalar resonance at $M \approx 1.3$ GeV. In the waves $\epsilon\pi$ and $f_0\pi$ at $M \approx 1.8$ GeV a clear resonance-like peak is observed. Our first results on this resonance were presented earlier in [3,4], the first observation of this structure was mentioned in [10]. The same object decaying into $K^+K^-\pi^-$ was seen in [11].

Relative phases of the waves $0^- S0 + \epsilon$ and $0^- S0 + f_0$ with respect to the $2^- S0 + f_2$ wave are also shown in Fig.4. Both of them have the decreasing part corresponding to the $\pi_2(1670)$ resonance in the $2^- S0 + f_2$ wave and the rising part corresponding to the $\pi(1800)$ resonance in the waves under study. There is no such structure in the $\rho\pi$ channel. As for $f_2\pi^-$ channel the signal which can be seen at $M \approx 1.7$ GeV is not considered as

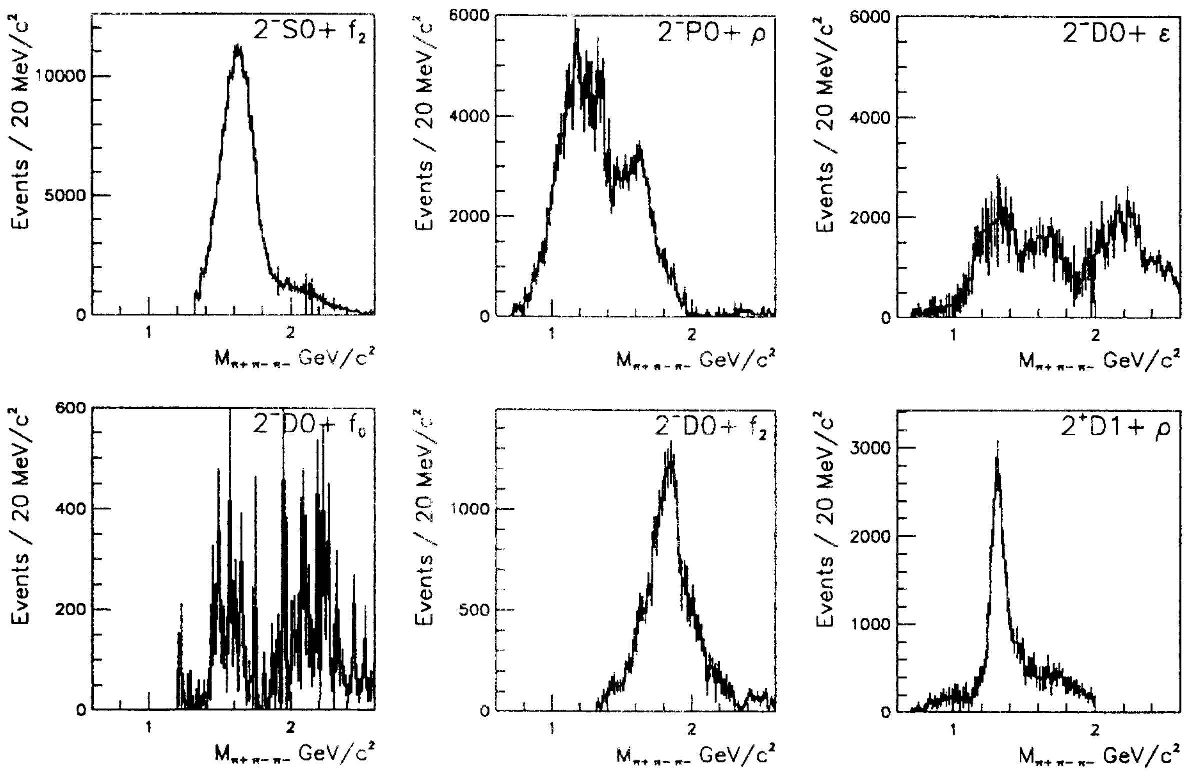

Fig. 3. Main $J^{PC} = 2^{-+}, 2^{++}$ waves.

significant by us due to its relatively small value and the dependence on the PWA model parameters.

For determination of the parameters of this object two different approaches were used. In the first case the amplitudes of the waves $0^- S0 + \epsilon$ and $0^- S0 + f_0$ were fitted together using BW functions with common mass and width and coherent polynomial or exponential background. In the second approach K-matrix formalism [15] was applied. The Deck background in Stodolsky form [16] and polynomial background were included into the fit. Results of the methods are consistent with each other and the following BW resonance parameters are obtained:

$$\begin{aligned} M &= 1775 \pm 7(stat) \pm 10(syst) \text{ MeV}, \\ \Gamma &= 190 \pm 15(stat) \pm 15(syst) \text{ MeV}. \end{aligned}$$

Significant systematic errors of the parameters are mainly caused by the choice of the background parameterization.

It should be noted that the widths and positions of the peaks in the waves $0^- S0 + f_0$ and $0^- S0 + \epsilon$ are slightly different. In our model it's described by the interference with the large background in the $0^- S0 + \epsilon$ wave.

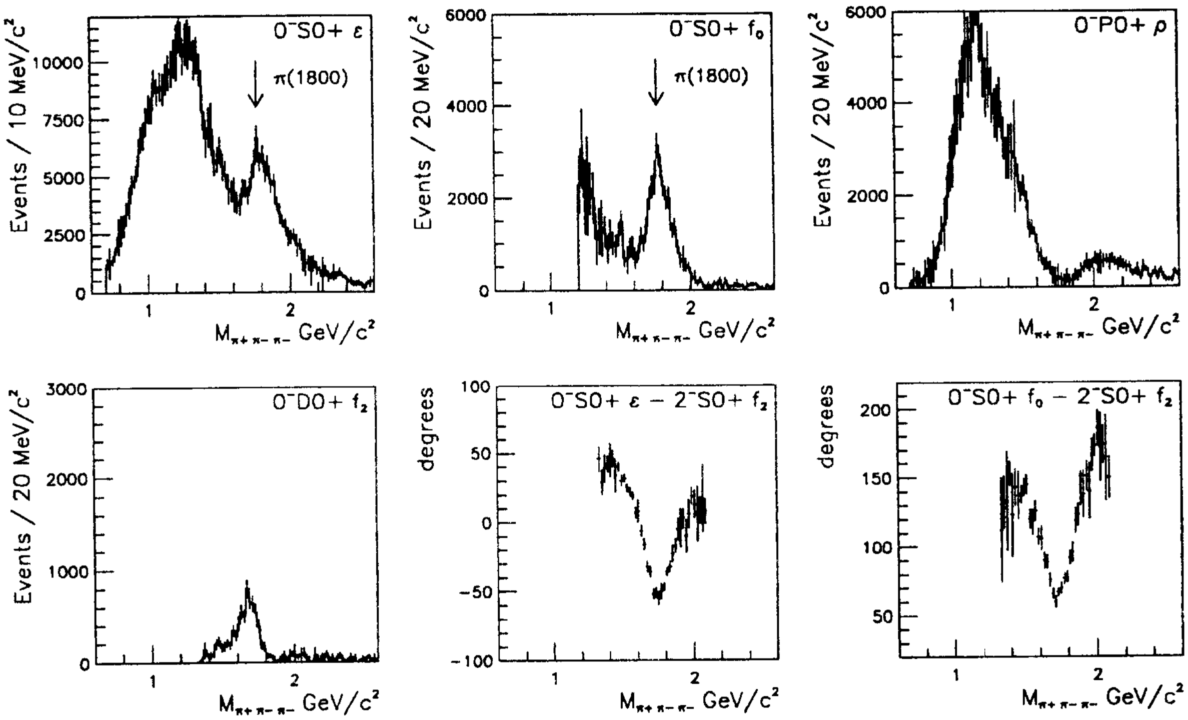

Fig. 4. Intensity of the wave with $J^{PC} = 0^{-+}$ in channels $\epsilon\pi$ (a), $f_0\pi$(b), $\rho\pi$(c), $f_2\pi$(d); relative phases of the waves $0^- S0 + \ \epsilon$ (e) and $0^- S0 + \ f_0$ (f) with respect to the $2^- S0 + \ f_2$ wave (see Fig.3).

The relative probability of the decay $\pi(1800)$ into $f_0\pi$ and $\epsilon\pi$ is

$$R = \frac{\Gamma(\pi^-(1800) \rightarrow f_0(\pi^+\pi^-)\pi^-)}{\Gamma(\pi^-(1800) \rightarrow \epsilon(\pi^+\pi^-)\pi^-)} = 1.7 \pm 0.3 .$$

This is an unexpectedly high value, since f_0 has a small width and a strong coupling to the strange quarks while ϵ is a wide object coupled mainly to the non-strange quarks. Another unusual feature of $\pi(1800)$ is its small width. This object is much narrower than $\pi(1300)$ which is considered as the first radial excitation of π-meson. The other peculiarity of this object is the suppression of the decay into $\rho\pi$ channel:

$$\frac{\Gamma(\pi(1800) \rightarrow \rho^0\pi^-)}{\Gamma(\pi(1800) \rightarrow f_0(\pi^+\pi^-)\pi^-)} < \ 0.14 \text{ at } 90\% \text{ C.L.}$$

The possible classification of $\pi(1800)$ can be the second radial excitation of π-meson. Nevertheless the above features of this object point to its possible exotic nature. In particular, all characteristics of $\pi(1800)$ can be naturally explained under assumption that it is a hybrid object [12]. One should note also that $\pi(1800)$ lies near the $P\bar{P}$ threshold, where the suppression of decay into $\rho\pi$ ($\rho\pi$-"puzzle") was seen in the $P\bar{P}$ annihilation at rest from the state $^{31}S_0$ [13]. We observe just the same suppression.

4. Conclusions

The partial-wave analysis has been performed for the reaction $\pi^- A \to \pi^+\pi^-\pi^- A$. The resonance with $I^G(J^{PC}) = 1^-(0^{-+})$ is clearly seen in this reaction. We have observed decays of this resonance in channels

$$\pi(1800) \to \epsilon(1300)\pi^-, \; f_0(975)\pi^- \text{ and } K^+K^-\pi^- \; [11]$$

with branching ratios

$$BR(f_0(\pi+\pi-)\pi^-) : BR(\epsilon(\pi+\pi-)\pi^-) = 1.7 \pm 0.3.$$

The parameters of the resonance are:

$$M = 1775 \pm 12 \text{ MeV} \quad \Gamma = 190 \pm 20 \text{ MeV}.$$

We have not observed its decay into $\rho^0\pi^-$ and K^*K [11].

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