INSTITUTE FOR HIGH ENERGY PHYSICS

IHEP 92-37
ОЭИУНК

S.I. Bityukov, G.V. Borisov, N.K. Vishnevsky,
E.V. Vlasov, Yu.P. Gouz, R.I. Dzhelyadin,
A.M. Zaitsev, Yu.M. Ivanyushenkov, A.N. Karyukhin,
I.A. Kachaev, G.A. Cluchnikov, V.F. Konstantinov,
A.K. Konoplyannikov,M.E. Kostrikov, V.V. Kostyukhin,
A.A. Kriushin,V.V. Lapin, V.D. Matveev, V.F. Obraztsov,
A.P. Ostankov, D.I. Ryabchikov, V.K. Semenov,
V.A. Sen'ko, M.M. Soldatov, E.A. Starchenko,Yu.A. Khokhlov,
IHEP, Protvino
G.M. Beladidze, T.A. Lomtadze, E.G. Tskhadadze
IPh, Tbilisi

Study of the process $\pi^- A \to \pi^- \eta' \eta\ A$ at the moment 36 GeV/c.

Submitted to *Soviet J. Nuclear Physics*

Protvino 1992

UDK 539.12 M–24

Abstract

Bityukov S.I. et al. Study of the process $\pi^- A \to \pi^- \eta' \eta\ A$ at the moment 36 GeV/c.: IHEP Preprint 92-37. — Protvino, 1992. — p.13 refs.: 8.

Reaction $\pi^- A \to \pi^- \eta' \eta\ A$ has been studied at 36 GeV/c beam momentum. The new state near the threshold of $\pi^- \eta' \eta$ decaying through the $\pi^- f_0(1590)$ has been observed. The combined analysis of two channels $\pi^- \eta\eta$ and $\pi^- \eta' \eta$ gives for branching ratio: $Br(X \to \pi^- \eta' \eta)/Br(X \to \pi^- \eta\eta) = 0.29 \pm 0.07$.

Аннотация

Битюков С.И. и др. Изучение процесса $\pi^- A \to \pi^- \eta' \eta\ A$ при импульсе 36 ГэВ. : Препринт ИФВЭ 92-37. — Протвино, 1992. —13 с., библиогр.: 8.

Изучена реакция $\pi^- A \to \pi^- \eta' \eta\ A$ при импульсе 36 ГэВ/с. В этой реакции вблизи порога $\pi^- \eta' \eta$ наблюдается объект, распадающийся на $\pi^- f_0(1590)$. Совместный анализ двух каналов $\pi^- \eta\eta$ и $\pi^- \eta' \eta$ дает для отношения вероятностей распадов: $Br(X \to \pi^- \eta' \eta)/Br(X \to \pi^- \eta\eta) = 0.29 \pm 0.07$.

© Institute for high energy physics, 1992.

The paper presents the results on selecting and studying the $\pi^-\eta'\eta$ system produced in the reaction

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

off berillium target at the π^- meson momentum 36 GeV/c. The experiment was carried out at the IHEP 70 GeV accelerator with the VES facility. For the description of the facility and the conditions for data acquisition refer to [1].

The $\pi^-\eta'\eta$ system was selected for two different channels of η' decay:

$$\eta' \to \pi^+\pi^-\eta \to \pi^+\pi^-\gamma\gamma \tag{2}$$

$$\eta' \to \rho^0\gamma \to \pi^+\pi^-\gamma \tag{3}$$

The η meson was detected by the $\eta \to \gamma\gamma$

Selection of the $\pi^-\eta'\eta \to \pi^-\pi^-\pi^+\eta\eta \to \pi^-\pi^+\pi^-\gamma\gamma\gamma\gamma$

The following selection criteria were imposed on the event in order to select channel (2):

- two negative particles and one positive leave the target;
- 4 showers with the energy $> 0.2\ GeV$, not associated with charged tracks, have been detected in the lead glass calorimeter;
- the remaining energy deposition in it (i.e. the energy of the showers not belonging to the four chosen ones and not associated with the charged tracks) is not greater than $0.4\ GeV$;
- the total energy of the event (the summed energy of the charged and neutral particles) is within the interval $34.5 < E_{tot} < 38\ GeV$
- among possible combinations of pair masses of four γ quanta there exists such combination, that the masses of both pairs occur within the interval $0.49 < m_{\gamma\gamma} < 0.63\ GeV$ (η meson mass range);

- any pair of four photons should not have an effective mass within π^0 mass range ($0.105 < M_{\gamma\gamma} < 0.165\ GeV$). This requirement was exploited to reduce the contribution from the background process $\pi^- A \to \pi^-\pi^+\pi^-\pi^o\pi^o A$.

Fig.1a presents the mass spectrum of $\pi^+\pi^-\eta$ for the events selected with these conditions (4 entries for event). A prominent η' signal is seen in effective mass distribution; its position corresponds to the tabulated value ($M_{\eta'} = 959 \pm 2$ MeV) and its width $\Gamma = 15.5 \pm 2.5$ MeV is determined mainly by the energy resolution of γ-detector. We applied 2C-fit for the selected events (fixing masses of both η-mesons) to improve mass resolution of $\pi^-\eta'\eta$-system.

Since the background under η' is rather large, we made statistical subtraction of background in all physical distributions given below, which means that for every distribution under consideration the argument (x-axis) was divided on equal bins and the mass spectrum of $\pi^+\pi^-\eta$ was produced for events from every bin. In obtained mass spectrum the number of η'-mesons was determined from the fit of it with the sum of Gauss distribution for η' signal and polynomial background. Thus obtained number of η' was filled in the corresponding bin of resulting histogram.

This method may be used here because:

- the shape of η'-meson signal depends only on the detector resolution and may be approximated by the Gaussian.
- the background under η' is smooth enough and may be described by the polynomial function with degree not bigger then 4.

Fig. 1b shows the mass spectrum of one pair of photons when the second pair is associated with the decay of $\eta' \to \pi^+\pi^-\eta \to \pi^+\pi^-\gamma\gamma$. This spectrum was obtained using the described method of background subtraction. In it the contribution from η-meson dominates and the background under it is small. This fact means that one does not need any other subtraction of background for the selection of channel (2) of reaction (1) and that obtained from the fit in every bin the number of η' corresponds to the number of events of the process (1).

Selection of the $\pi^-\eta'\eta \to \pi^-\rho^0\gamma\eta \to \pi^-\pi^+\pi^-\gamma\gamma\gamma\gamma$

The following selection criteria were imposed on the event in order to select channel (2):

- two negative particles and one positive leave the target;

- 3 showers with the energy $> 0.2\ GeV$, not associated with charged tracks, have been detected in the γ detector;
- the remaining energy deposition in the γ detector is not greater than $0.4\ GeV$;
- the total energy of the event is within the interval $34.5 < E_{tot} < 38\ GeV$;
- among possible combinations of pair masses of three γ quanta there exists such combination, that the mass of two photons occurs within the interval $0.49 < m_{\gamma\gamma} < 0.63\ GeV$ (η meson mass range) and the energy of the third photon is greater then 2 GeV. Such a threshold for the energy of the free photon is required to decrease in the final sample the contribution of the process $\pi^- A \to \pi^-\pi^+\pi^-\eta A$ with the background signal in γ-detector interpreted as the additional photon;
- among possible combinations of pair masses of three photons there should not be such combination, at which the mass of some pair would be within the interval $0.105 < M_{\gamma\gamma} < 0.165\ GeV$ (π^o meson mass range).

Fig.2a presents the mass spectrum of the $\pi^+\pi^-\gamma$ system for the selected events. Two signals from η and η' mesons, decaying along the $\pi^+\pi^-\gamma$ channel are clearly seen in the spectrum. It should also be noted that the contribution from ω and η, decaying into $\pi^+\pi^-\pi^o$, with one of the photons missing, is rather small, which shows the capability of the setup to select the events with single photon in the final state. The background under η' meson is large, therefore, similar to the case with channel (2) a statistical background subtraction was made for all distributions below. The $\pi^+\pi-$ mass spectrum from the $\eta' \to \pi^+\pi^-\gamma$ system is given in fig.2b. As is seen from this spectrum the $\pi^+\pi^-$ system produces ρ^o meson, which is in agreement with other data on the $\eta' \to \pi^+\pi^-\gamma$ [2,3]. The mass spectrum of two photons, when the third one is associated with the $\eta' \to \pi^+\pi^-\gamma$ decay, is presented in fig.2c. Similar to channel (2), the signal from η is dominating here, and there is practically no background under it. Hence, the account of the background under $\eta' \to \pi^+\pi^-\gamma$ is sufficient for the selection of the $\pi^-\eta'\eta$ system in channel (3).

Physical analysis of the $\pi^-\eta'\eta$ system

After applying all the selection criteria we finally have 630±50 events in channel (2) and 1300±130 events in channel (3). With an account of the detection efficiency the branching ratio for the η' decay channels is equal to $Br(\eta' \to \pi^+\pi^-\gamma)/Br(\eta' \to \pi^+\pi^-\eta) = 0.76 \pm 0.12$, which agrees with the tabulated value [2].

All the physical distributions of process (1) obtained for channels (2) and (3) are compatible with each other within the errors and they differ only in the absolute normalization (e.g., fig.3a,b presents the $\eta\eta'$ mass spectrum for channels (2) and (3), respectively). Consequently in what follows we shall give all the results for the weighted sum of the two channels (i.e. each distribution is corrected for the detection efficiency and tabulated value of the decay probability, and then it is averaged with an account of the errors).

Fig.3a presents the $\eta'\eta$ mass spectrum, where one can distinguish a narrow threshold structure at $M \simeq 1.55\ GeV$. According to results of work [4] in which $\eta\eta'$-system have been studied in charge exchange reaction, we shall call this structure $f_0(1590)$-meson (see [2]). The distribution over the angle between π^- and η in the $\eta'\eta$ c.m.s. for the events with $M_{\eta'\eta} < 1.71\ GeV$ is given in fig.4a, it points to the fact that in the $\eta'\eta$ system at $M_{\eta\eta'} < 1.71$ GeV it is the wave with $J^P = 0^+$ that dominates here. When fitting our distributions with the sum of relativistic Breit-Wigner distribution (for J=0) and smooth background, we obtained the following parameters $M_{f_0} = 1.550 \pm 0.045 \pm 0.030(syst)\ GeV, \Gamma_{f_0} = 0.153 \pm 0.067 \pm 0.050(syst)\ GeV$, which agrees with the tabulated parameters of $f_0(1590)$ [2]. The fitting results are presented in fig.3c with a solid line. The production probability for $f_o(1590)$ in reaction (1) is equal to $0.5 \pm 0.1 \pm 0.1(syst)$.

The $\pi^-\eta'\eta$ spectrum is shown in fig. 5a. Here a peak with the parameters $M = 1.873 \pm 0.033 \pm 0.020(syst)$ GeV, $\Gamma = 0.225 \pm 0.035 \pm 0.020(syst)$ GeV may be singled out (the result of fit with the sum of the Breit-Wigner distribution and polynomial background is imposed onto the histogram). A two-dimensional distribution of the number of events versus $M_{\eta\eta'}$ and $M_{\pi^-\eta\eta'}$ is given in fig.5b. These data are in favour of a big correlation between the production of the structure in the $\pi^-\eta'\eta$ system and threshold structure in the $\eta\eta'$ system. Hence if one selects the events with $M_{\eta\eta'} < 1.71$ GeV and single out the signal from f_o (1590), then the peak in the $\pi^-\eta'\eta$ spectrum remains almost without background (see fig.5c). And it is vice versa, if one chooses only large masses for $\pi^-\eta'\eta$: $M_{\pi^-\eta'\eta} > 2.07$ GeV, then the near-threshold enhancement in the $\eta'\eta$ spectrum vanishes (see fig.5d). So it is natural to suggest that in reaction (1) the production of the structure, decaying into $\pi^- f_0(1590)$ is observed.

This assumption becomes even stringer, since the $\pi^-\eta'\eta$ system at $M_{\pi^-\eta'\eta} < 2.07\ GeV$ has a large component with a non-zero total momentum, which can hardly be expected near the threshold of $\pi^-\eta'\eta$, the resonance being absent. The $cos(\Theta_{GJ})$ distribution where Θ_{GJ} is the polar angle of π^- in the Gottfried-Jackson system of $\pi^-\eta'\eta$ is shown in fig.4b. This distribution is significantly differs from the smooth one ($\chi^2/NDF = 6.0$ in fitting the distribution with the

constant), which implies that the total moment of the observed object is not zero.

Since $f_0(1590)$ meson is observed both in the $\eta\eta'$ and in $\eta\eta$ mode, it would be useful to analyze the two systems together which would greatly help in understanding the nature of the observed object and in interpreting it as a bound $\pi^- f_o(1590)$ state. The $\pi^-\eta\eta$ system was also singled out and studies at the VES facility [1] and there was found the $X(1814)$ state with the mass $M = 1814 \pm 27$ MeV and with $\Gamma = 205 \pm 35$ MeV. Its most probable quantum numbers are $J^P = 1^+$ or 2^- The object observed in the $\pi^-\eta\eta'$ system has the same width and a little bigger mass. The $cos\Theta_{GJ}$ distribution (fig.4b) does not contradict the $J^P = 1^+$ or 2^- hypothesis. The distribution over the transferred momentum squared $|t-t_{min}|$ coincides with a similar distribution for the $\pi^-\eta\eta'$ system (see fig.6), and in both cases the narrow t-distribution points to a diffraction production mechanism of the object off nucleus. Proceeding from what has been said above it would be natural to assume that we have observed the decays of the same resonance in the channel $\pi^-\eta\eta'$ and $\pi^-\eta\eta$. Then the shift of the resonance in the $\pi^-\eta\eta'$ channel may be caused by a barrier factor. The displacement depends on the unknown decay mechanisms for the channels $\pi^-\eta\eta'$ and $\pi^-\eta\eta$. The model calculations, however, show that the expected shift scale agrees with the one observed. The branching ratio for the X(1814) object decay along two channels, determined by the number of the events in the peak, is equal to

$$Br(X \to \pi^-\eta'\eta)/Br(X \to \pi^-\eta\eta) = 0.29 \pm 0.07 \qquad (4)$$

For the processes with light quarks, no strange particles participating, the ratio of coupling constants squared of η' and η with hadrons should not depend on the reaction and numerically it is equal to $K \approx 0.5$ [5]. This result has been obtained in the frame of the quark lines rule and is confirmed by numerous processes such as : η' and η production in the charge exchange reactions [6], in the $J/\psi \to \rho\eta', J/\psi \to \rho\eta$ decays (see [2]), in the $A_2(1310) \to \pi^-\eta', A_2 \to \pi^-\eta$ decays [7], etc. On the other hand such ratio is considerably violated in the processes where a large contribution from annihilation diagrams to the final states is expected (as an example we can mention here the branching ratio for the $J/\psi \to \gamma\eta'$ and $J/\psi \to \gamma\eta$ decays [2], the $f_o(1590) \to \eta'\eta$ and $f_o(1590) \to \eta\eta$ [4,8]).

Fig.7a shows the dependence of the magnitude K on the $\eta\eta$ or $\eta\eta'$ system mass. It was obtained with the formula

$$K = \frac{\frac{d\sigma(\pi^- \eta\eta')}{dm_{\eta\eta'}}}{\frac{d\sigma(\pi^- \eta\eta)}{dm_{\eta\eta}}} \times \frac{\Phi_2(\eta\eta)}{\Phi_2(\eta\eta')} \tag{5}$$

($\Phi_2(\eta\eta'), \Phi_2(\eta\eta)$ stands for the $\eta\eta', \eta\eta$ phase space). This formula is valid for the S-wave in the $\eta\eta'$ and $\eta\eta$ systems and gives a lower estimate for K in the presence of other waves. As is seen from fig.7a the $\eta'\eta$ production goes more intensely in the vicinity of the threshold as compared with that of $\eta\eta$. A similar procedure was used to find out the dependence of K on the three particle mass of the $\pi^-\eta'\eta$ and $\pi^-\eta\eta$ system. In this case to estimate the value for K the ratio of the production cross sections of the $\pi^-\eta'\eta$ and $\pi^-\eta\eta$ systems was divided into a ratio of their phase spaces. Hence fig.7b plots thus obtained value for K versus the three particle mass of $\pi^-\eta'\eta$ ($\pi^-\eta\eta$). In the region of X(1814) the value of K is higher than that predicted by the quark model, and, on the other hand, it agrees with the prediction in the region of large masses.

These observed peculiarities in the value for K find their most natural explanation under the assumption that X(1814) decays into $\pi^- f_0(1590)$, since no matter what the nature of $f_o(1590)$ is, the probability of its decay into $\eta'\eta$ is much more higher than in the case of $\eta\eta$.

Conclusions

In the $\pi^-\eta'\eta$ system an object is observed near the threshold whose parameters correspond to those of the $X(1814)$ state earlier selected in the $\pi^-\eta\eta$ system [1]. Its production is associated with the production of the threshold structure in $\eta\eta'$ system whose parameters coincide with that of $f_0(1590)$-meson. The cross sections ratio for reaction (1) and $\pi^- A \to \pi^-\eta\eta A$ reaction in the region of X(1814) and $f_o(1590)$ significantly differs from the predictions obtained in the framework of the quark lines rules [5]. The whole set of these data is in favour of the prediction put forward in [1], which concerns the exotic nature of the X(1814) object.

In conclusion the authors would like to express their gratitude to S.S. Gershtein and Yu. D. Prokoshkin for useful and fruitful discussions of the paper. We are also indebted to the stuff of IHEP, who provided reliable operation of the accelerator and helped us in the VES experiment.

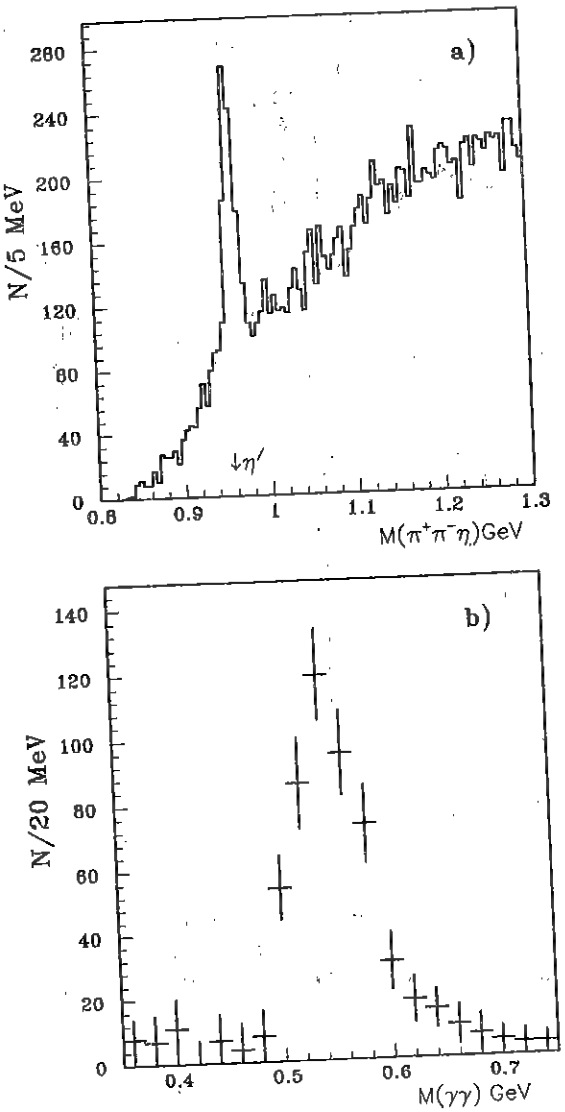


Fig.1a. Mass spectrum of the $\pi^+\pi^-\eta$ system
b. Mass spectrum of $\gamma\gamma$ pair for the events with $\eta' \to \pi^+\pi^-\eta$ decay.

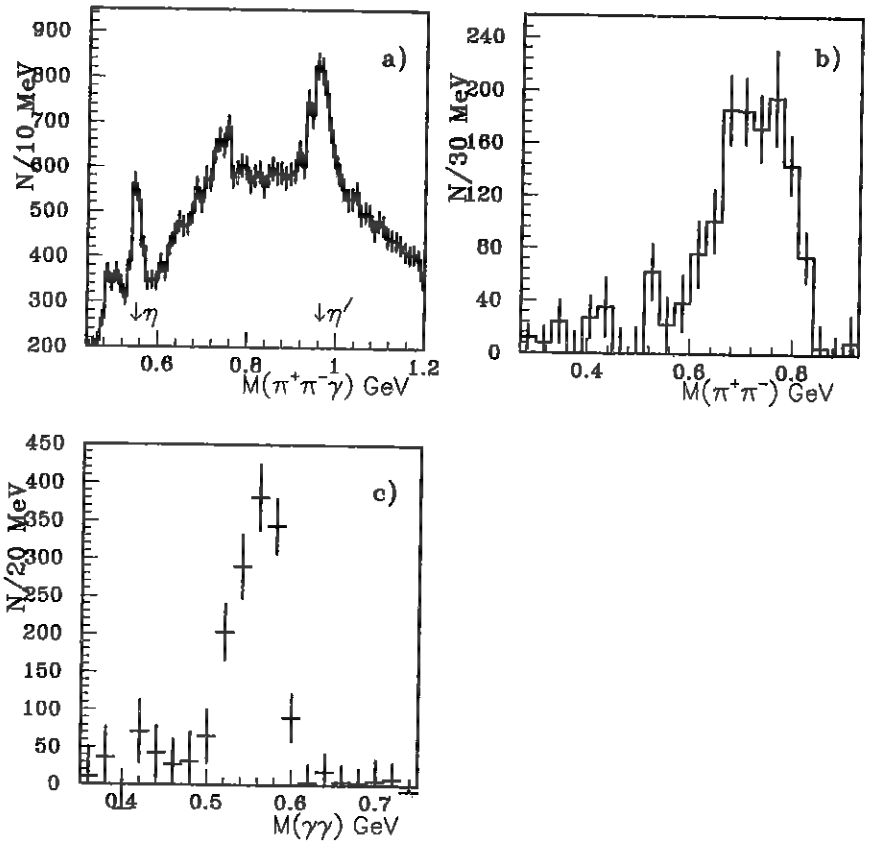


Fig 2a. Mass spectrum of the $\pi^+\pi^-\gamma$ system
b. $\pi^+\pi^-$ mass spectrum from the $\eta' \to \pi^+\pi^-\gamma$
c. $\gamma\gamma$ mass spectrum for the events with $\eta' \to \pi^+\pi^-\gamma$ decay

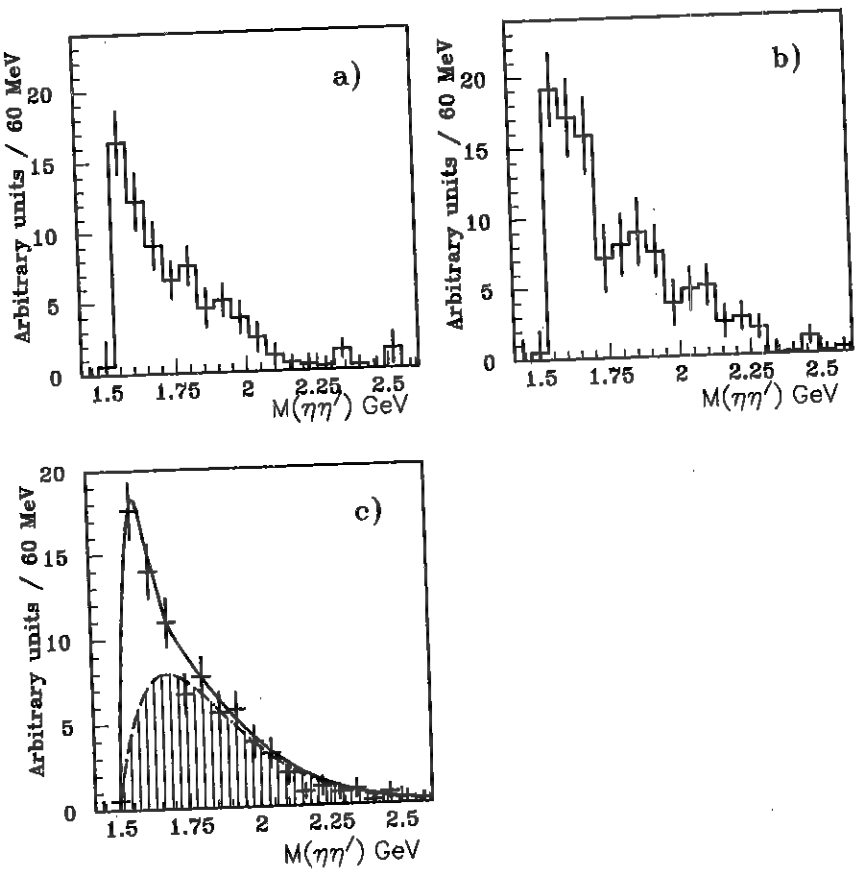


Fig.3 $\eta'\eta$ mass spectrum

a) η' is detected by the $\eta' \to \pi^+\pi^-\eta$ decay;

b) η' is detected by the $\eta' \to \pi^-\pi^-\gamma$ decay.

c) Weighted sum of two channels.A solid curve corresponds to the fit with the sum of Breit-Wigner distribution (for J=0) and smooth background. The dashed area shows the behaviour of the background under the resonance.

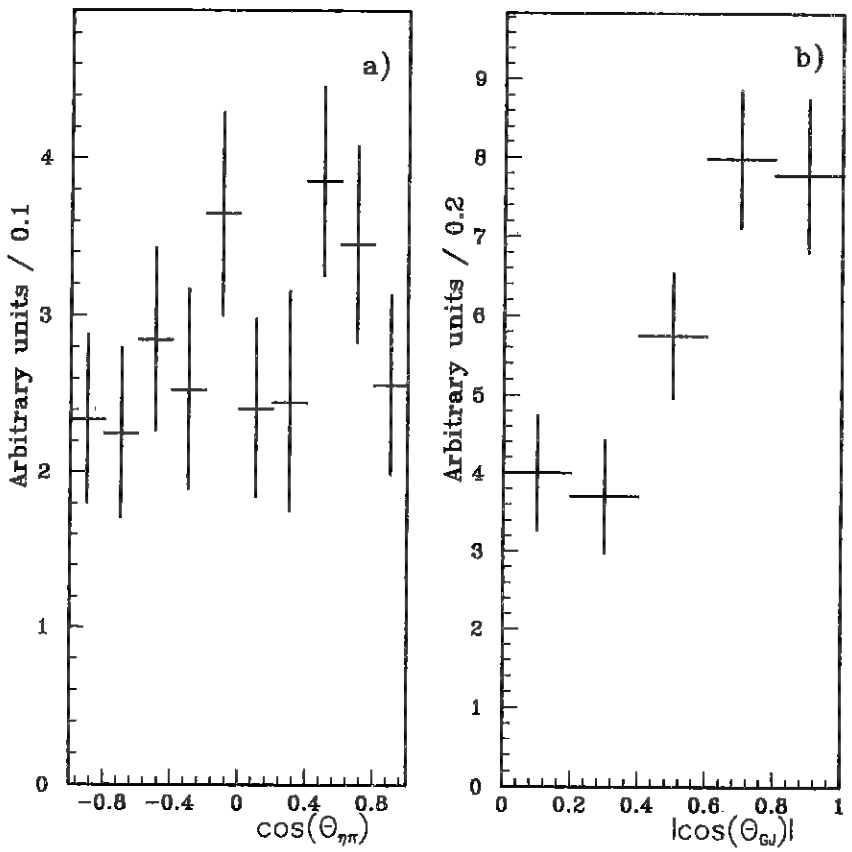


Fig.4a. The Cos($\Theta_{\pi\eta}$) distribution; $\Theta_{\eta\pi}$ is the angle between η and π^- in the $\eta'\eta$ rest frame.

b. The distribution over the π^- emission angle in the Gottfried- Jackson frame.

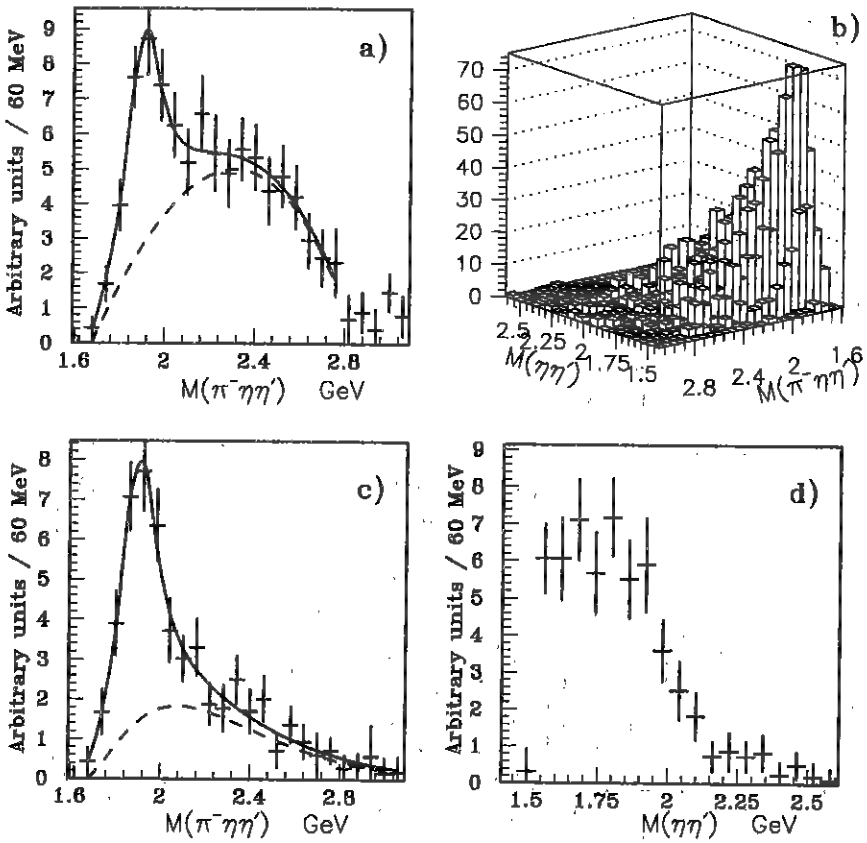


Fig.5a. Mass spectrum of the $\pi^-\eta\eta'$ system. Solid curve corresponds to the fit with the sum of Breit -Wigner distribution and smooth background.

b. $M_{\pi^-\eta\eta'} - M_{\eta'\eta}$ biplot .

c. Mass spectrum of the $\pi^-\eta\eta'$ system, when $M_{\eta\eta'} < 1.71$ GeV. Solid curve corresponds to the fit with the sum of Breit -Wigner distribution and smooth background. Broken line - background behaviour.

d. The $\eta\eta'$ mass spectrum when $M_{\pi^-\eta\eta'} > 2.07$ GeV.

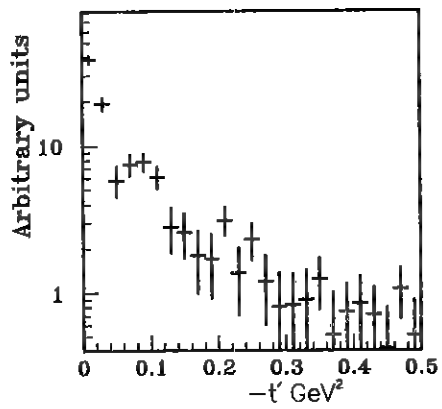
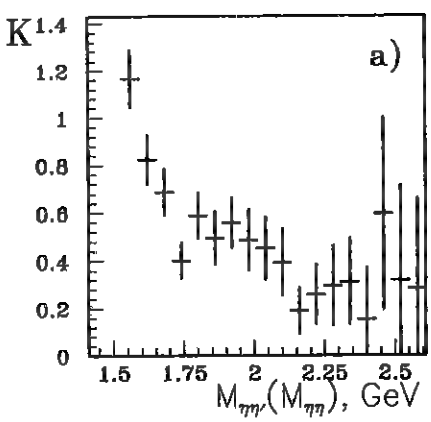


Fig. 6



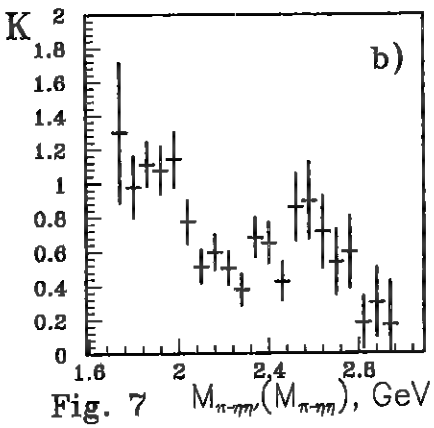


Fig. 7

Fig.6. The $-t = |t - t_{min}|$ distribution of the $\pi^-\eta\eta'$ system.

Fig.7a. The K-dependence (see formula(5)) versus $M_{\eta\eta'}(M_{\eta\eta})$.

b. The ratio of the production cross sections of the $\pi^-\eta\eta'$ and $\pi^-\eta\eta$ divided by their phase space ratio versus $M_{\pi^-\eta'\eta}(M_{\pi^-\eta\eta})$.

References

[1] S.I.Bityukov et al.// Phys.Lett. 1991 v.268B p.137.

[2] Particle Data Group // Phys.Lett. 1990 v.239B p.1.

[3] S.I.Bityukov et al. // Sov. J. Nucl. Phys. 1991 v.54 p.529.

[4] F.G.Binon et al. // Nuovo Cimento, 1984 v.80A p.363.

[5] S.Okubo et al. // Phys.Rev. 1977 v.D15 p.177.

[6] F.G.Binon et al. // Sov. J. Nucl. Phys. 1983 v.38 p.934

[7] S.I.Bityukov et al. // Preprint IHEP 91-95, to be published in Z.Phys. C

[8] F.G.Binon et al. // Nuovo Cimento, 1983 v.78A p.313.

Received March 13, 1992

С.И.Битюков и др.
Изучение процесса $\pi^- A \to \pi^- \eta' \eta A$ при импульсе 36 ГэВ.
Редактор А.А.Антипова. Технический редактор Л.П.Тимкина.

Подписано к печати 17. 03. 92. Формат 60x90/16.
Офсетная печать. Печ.л. 0,81. Уч.-изд.л. 0,96. Тираж 270.
Заказ 269. Индекс 3649 Цена 1 руб. 40 коп.

Институт физики высоких энергий, 142284, Протвино
Московской обл.

I руб. 40 коп. Индекс 3649

П Р Е П Р И Н Т 92-37, И Ф В Э, 1992