Study of the $K^+K^-\pi^+\pi^-\pi^0$ final state in antiproton annihilation at rest in gaseous hydrogen at NTP with the OBELIX spectrometer

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Abstract

A spin-parity analysis of a sample of $\bar{p}p \to K^+K^-\pi^+\pi^-\pi^0$ annihilation events taken at rest in gaseous H_2 at NTP is reported. The invariant mass spectrum of the $K^+K^-\pi^0$ system shows the presence of the E/ι resonance pattern at 1.42 GeV. The analysis of this signal confirms the results obtained by the OBELIX Collaboration in previous works, namely: the existence of two pseudoscalar states at 1.413 $\pm$ 0.002 and 1.460 $\pm$ 0.012 GeV with widths 0.051 $\pm$ 0.004 and 0.120 $\pm$ 0.015 GeV, respectively. The $\bar{p}p$ system in the $^3P_1$ wave shows also a signal corresponding to the axial vector $f_1(1420)$ decaying to $K^*\bar{K}$ with mass 1.420 $\pm$ 0.003 GeV and width 0.061 $\pm$ 0.005 GeV. A study of the incoherent phase space background shows that its origin is mostly due to the reflection of a resonant state in the $K^+K^-\pi^+\pi^-$ system. The isobar decomposition of this resonant state is mainly $f_0(1370)(\pi\pi)_S$, its parameters are: $J^{PC} = 0^{++}$, $m = 1.670 \pm 0.02$ GeV and width 0.267 ± 0.036 GeV. This signal can be probably identified with another decay mode of the $f_0(1710)$.

1 Introduction

The interest to the pattern of resonant states in the E/ι region lies in the fact that some of these objects could be exotica, i.e. non-$q\bar{q}$ mesons [1,2]. For a detailed review see [3].

Most of the work performed at LEAR on the E/ι case has been carried out by the OBELIX experiment [4–6], which investigated the $K\bar{K}\pi$ final state, the only one which allows to study the full pattern of resonances in the interested

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mass region. A contribution is also due to the Crystal Barrel experiment, which investigated the channel $\eta\pi\pi$ [7,8].

In the present paper, the investigation of the channel $\bar{p}p \rightarrow K^+K^-\pi^+\pi^-\pi^0$ in gaseous hydrogen at NTP, to continue the study of the E/ι to $K\bar{K}\pi$ decay modes, is reported.

A spin-parity analysis was performed, according to which the results of the previous OBELIX results [4–6] were again fully confirmed, and precisely: two pseudoscalar states were seen at 1.41 GeV and 1.45 - 1.46 GeV, with widths 0.05 GeV and 0.110 $\div$ 0.125 GeV, respectively. The first pseudoscalar decays to $a_0\pi$, $K^*\bar{K}$, but mainly directly to $K\bar{K}\pi$; the second one decays only to $K^*\bar{K}$. In $^3P_1$ protonium wave a signal was seen corresponding to the axial vector $f_1(1420)$ decaying to $K^*\bar{K}$ with mass and width 1.42 GeV and 0.06 GeV, respectively.

A new interesting result came out from the present analysis studying the nature of the incoherent phase space background; this background was found unexpectedly large, of the order of 50% against an expected 15%. It turned out that its origin was mostly due to the reflection of a resonant state in the $K^+K^-\pi^+\pi^-$ system. This resonant state, with scalar quantum numbers, observed in the $K\bar{K}\pi\pi$ system for the first time, can be tentatively identified with an other decay mode of the $f_0(1710)$ [9]. Nature and spin assignment of the $f_0(1710)$ were controversial until recently, its interpretation ranging from a glueball to a molecular state [10].

2 Data taking and event selection

About 24 millions antiproton-proton annihilations at rest on a gaseous hydrogen target at NTP were collected in 1995 using the OBELIX spectrometer, at CERN LEAR. The OBELIX experimental setup consisted of four detectors having cylindrical geometry (a detailed description can be found in Ref. [11]), arranged between the poles of the Open Axial Field Magnet (OAFM) of CERN. In the present analysis only TOF (Time Of Flight) and JDC (Jet Drift Chamber) detectors were exploited. The data were collected with a 4-prong trigger, asking multiplicity 4 in the inner TOF and 3 or 4 in the outer TOF barrels. In addition, it was required the presence of at least one particle with a time of flight, between the internal and external barrels, larger than 8.5 ns, in order to record data with a larger fraction of charged kaons in the final state.

The events were reconstructed using the OBELIX reconstruction program and the charged particles were identified through their energy deposition in the JDC. The kaon and pion identification efficiencies were optimised by defining contour regions in the dE/dx versus momentum scatter plot with uniform confidence level. The residual pion contamination of the kaon sample was thus below 1% in the momentum interval of interest (below 400 MeV/c).

The 9682 selected events were submitted to a one-constraint kinematical fit to test the hypothesis $\bar{p}p \rightarrow K^+K^-\pi^+\pi^-\pi^0$. Events with a confidence level greater than 90% were retained for further analysis. Contamination from other final states was minimised by rejecting events satisfying concurrent kinematical hypotheses. A residual 8% contamination was estimated by comparing the experimental χ^2 distribution to the theoretical one with one degree of freedom.

The apparatus acceptance for events of the type $\bar{p}p \rightarrow K^+K^-\pi^+\pi^-\pi^0$ was evaluated by using the OBELIX Monte Carlo program based on the GEANT 3.21 simulation package.

The scatter plot of the squared mass of the $\pi^+\pi^-\pi^0$ system versus that of the K^+K^- system is shown in Fig. 1a for the selected events. The $\pi^+\pi^-\pi^0$ invariant mass (Fig. 1b) is dominated by the presence of two signals in the mass regions around 0.5 GeV and 0.8 GeV, corresponding to the production of the η and ω resonances. The ω signal is very much reduced by the OBELIX apparatus acceptance, due to the undetection of the low momentum (< 0.2 GeV/c) charged kaons, causing the depletion of events with large values of the $\pi^+\pi^-\pi^0$ invariant mass. A signal corresponding to the ϕ-meson is visible in the K^+K^- invariant mass spectrum (Fig. 1c) together with a second peak at 1.1 GeV, which is a kinematical reflection due to the ω resonance. The $\bar{p}p \rightarrow \omega\phi$ channel cannot be observed in the OBELIX setup due to a combined effect of kinematics (the ϕ is produced quasi at rest) and of the apparatus cut on the low momentum kaons.

In the $K^+K^-\pi^0$ invariant mass spectrum of Fig. 2 one observes an enhancement around 1.4 GeV corresponding to the E/ι signal. This signal becomes more evident when events associated to η and ω production are removed from the data sample by making an appropriate selection of the $\pi^+\pi^-\pi^0$ invariant mass ($0.610 < m_{\pi^+\pi^-\pi^0} < 0.730$ GeV). After this cut the data sample reduces to 3651 events.

The main feature of the $K\pi$ invariant mass distributions, Fig. 3, is the presence of the charged $K^{*\pm}(892)$ and the absence of the neutral $K^{*0}(892)$. This 'asymmetry' was checked as neither being induced by the apparatus acceptance nor by selection cuts. An interpretation of this feature is that there is no K^* direct production. It will be shown in the following section that indeed charged K^* are coming mainly from E/ι decay.

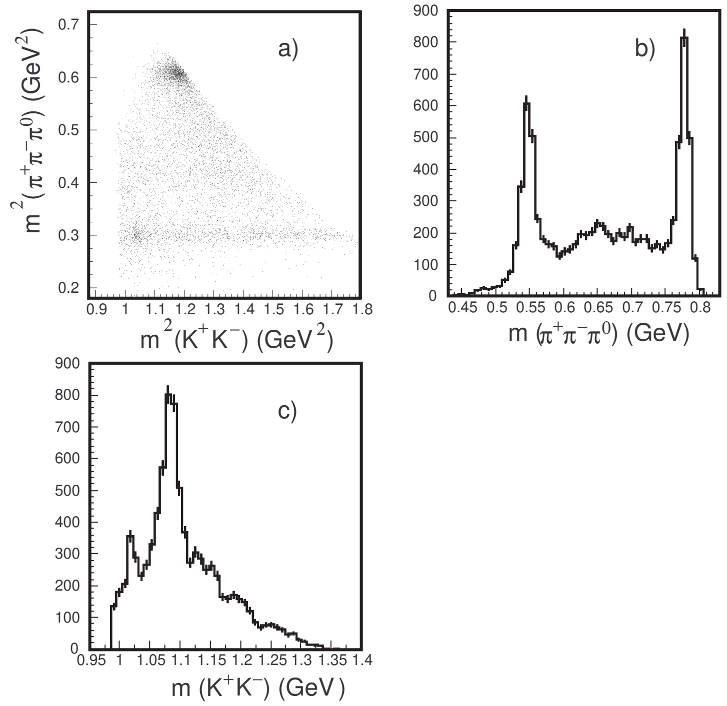

Fig. 1. *a) Scatter plot of $m^2(\pi^+\pi^-\pi^0)$ versus $m^2(K^+K^-)$; b) $\pi^+\pi^-\pi^0$ invariant mass; c) K^+K^- invariant mass.*

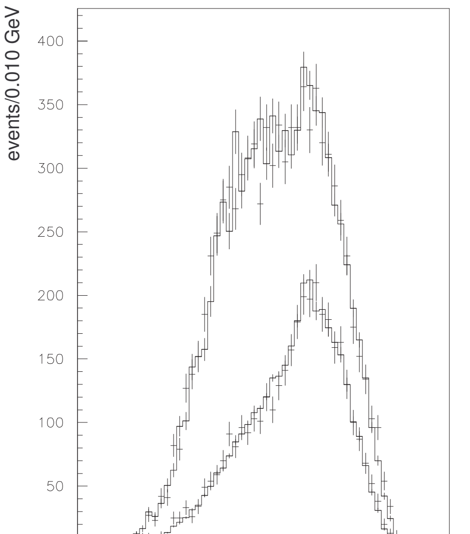

Fig. 2. *$K^+K^-\pi^0$ invariant mass spectrum for the two data samples: with and without η, ω. The line superimposed to the experimental points is the result of the best fit.*

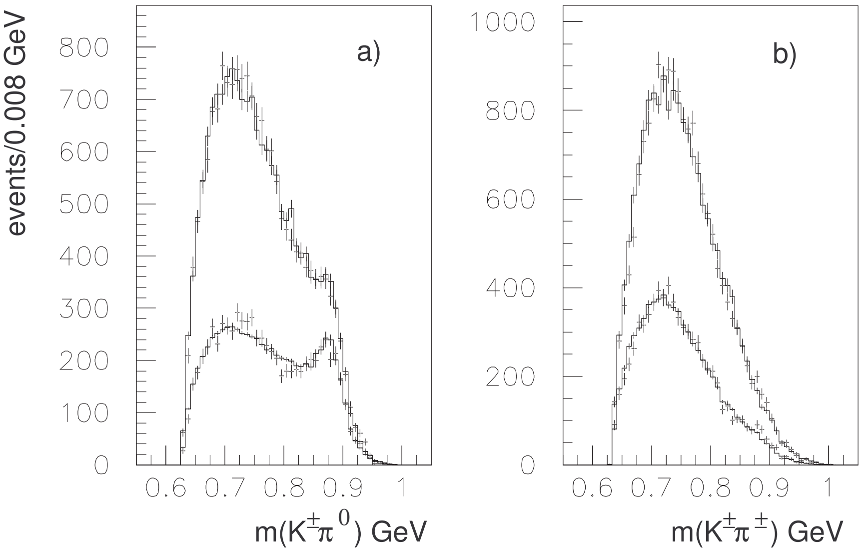

Fig. 3. *Charged and neutral $K\pi$ invariant mass spectra for the full and reduced (without η and ω) data samples. The line is the result of the best fit.*

3 Spin-parity analysis

3.1 Global fit

A spin-parity analysis of the selected $K^+K^-\pi^+\pi^-\pi^0$ data sample was performed within the framework of the isobar model, using Zemach tensor formalism, relativistic BW for resonance amplitudes, as well as amplitudes in the scattering length approximation for low energy two body scattering (as for $\pi^+\pi^-$). The spin-parity formalism together with the fitting procedure was already described in detailed in previous works [4,5] of the Collaboration.

The first step in the spin-parity analysis consisted in fitting the reduced data sample (without η and ω). A global fit of these 3651 events was done with an amplitude similar to the best fitting amplitude used to describe the data samples $K^\pm K^0\pi^\mp\pi^+\pi^-$ of the previous works, and constructed in terms of two isobars: the $K\bar{K}\pi$ system recoiling against an isoscalar $\pi\pi$ S-wave. Then, for the ${}^1S_0$ $\bar{p}p$ partial wave contributions to the $K\bar{K}\pi$ isobar two pseudoscalars were considered: the $\eta(1400)$, decaying to $a_0\pi$, $K^*\bar{K}+c.c.$ and direct $K\bar{K}\pi$ three-body decay, and the $\eta(1460)$, decaying to $K^*\bar{K}+c.c.$ For the ${}^3P_1$ protonium wave contributions from a 1^{++} resonance were considered, the $f_1(1420)$, decaying to $K^*\bar{K}+c.c.$, plus a direct $K^*\bar{K}$ production. Since the $f_1(1285)$ was practically unobserved in the reduced data sample, its contribution was not taken into account at this stage. Finally, the fitting amplitude contained also an incoherent phase-space background term (the background shape was tested in dedicated analyses). Masses and widths of the resonances were fixed to the values obtained in the previous published analyses of the $KK^0\pi\pi\pi$ channel, and the number of free parameters was varied between 5 and 8, depending on the testing hypothesis. The quality of the fit was established by evaluating $\mathcal{L}$= -logL, the logarithm of the likelihood function used for the minimisation, as well as from the χ^2 calculated over several invariant mass distributions. The theoretical amplitude constructed in this way provided a reasonable description of the experimental data; however, the result of the minimisation procedure indicated a poor quality of the fit: $\chi^2/N_{DOF} = 1600/1126$ with $\mathcal{L}$ ranging from -2040 to -2100. Moreover, the result suggested an incoherent background of the order of $(54 \div 56)\%$, which appeared unexpectedly large, indicating an incomplete description of the decay amplitude. In fact, the total background is due to the contamination from other reactions (estimated around $8\div10\%$) and from the contributions to the overall amplitude neglected in the analysis.

In a second series of fits the full data sample (8598 events) was used. In this case, the fitting amplitude contained in addition the contribution of ηK^+K^- and ωK^+K^- intermediate states, where the K^+K^- system can be in relative S (like f_0 and a_0) or P (like $\phi(1020)$) angular momentum states. The question of which $K\bar{K}$ system is produced with ω can be addressed. It might be a complicated superposition of many resonances or free production of two uncorrelated kaons. As it was reported in the previous section, low momentum kaons could not be detected by the apparatus and therefore channels like $\bar{p}p \to \omega\phi$ or $\bar{p}p \to \omega a_0$ could not be measured. One has then to look to greater $K\bar{K}$ mass systems. The best fit result was that K^+K^- are coming from $f_0(1370)$. The main contributions to the full data sample, besides the complex E/ι structure, are: $\eta f_0(1370)$, from initial $^1S_0$ and $^3P_1$ and the amplitudes $\omega f_0(1370)$ and $\eta\phi(1020)$, from initial $^3S_1$ and $^1P_1$, respectively. With $f_0(1370)$ is indicated the $K\bar{K}$ isobar in $L = I = 0$ state [9] which has been parameterised in different ways, the best one being that of a broad resonance with mass around 1.4 GeV and width of $\sim$ 200 MeV. These values were obtained from the fit leaving mass and width as free parameters. Other contributing amplitudes were even considered: from the initial state $^3S_1$ the $\eta\phi(1020)$ channel and from the $^1P_1$ state the $\omega f_0(1370)$. The contribution of the ηa_0 channel was also taken into account. All contributions were found to be negligible.

The fit (with 12 free parameters) of the full data sample was not yet satisfactory ($\mathcal{L} = -11890$ and χ^2/N_{DOF}=1755/1250). Still the background contribution turned out too large ($\sim$26%). The fit of the reduced data sample, using this more complex amplitude, gave again a too large background contribution even if it provided a qualitatively good description of all the invariant

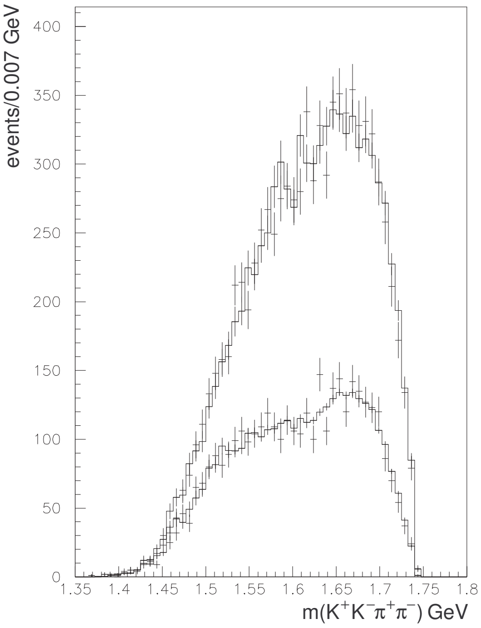

Fig. 4. $K^+K^-\pi^+\pi^-$ *invariant mass spectrum for the full and reduced (without* η *and* ω*) data samples. The line is the result of the best fit.*

mass distributions. The only spectrum poorly fitted was the $K^+K^-\pi^+\pi^-$ invariant mass ($\mathcal{L}$=-2220 and χ^2/N_{DOF}=1454/1126). The larger discrepancies were around 1.68 GeV where an enhancement, associated to a peak at 0.17 GeV/c in the π^0 momentum distribution, was observed in the experimental distribution (Fig. 4).

From these studies, it was concluded that a contributing term in the transition amplitude was still missing. The possible source of the large background was analysed separately in a series of fits using mainly the reduced data sample (without η and ω) where the background relative contribution was larger. By inspecting the $K^+K^-\pi^+\pi^-$ invariant mass distribution (Fig. 4) it was proven that the shoulder around $\sim$ 1.7 GeV was not due to an acceptance effect.

In order to construct the most appropriate isobar decomposition of the $K\bar{K}\pi\pi$ system, the following hypotheses were individually tested: $(K\pi)_S(K\pi)_S$, $K^{*0}\bar{K}^{*0}$, $f_0(1370)(\pi\pi)_S$. It was assumed J^{PC}=0^{++} for $K\bar{K}\pi\pi$ produced from the initial states $^1S_0$ and $^3P_1$. The $K^{*0}\bar{K}^{*0}$ hypothesis gave a substantial improvement of the fit quality even if its partial contribution was small (confirmed by the absence of K^{*0} signal in the $K\pi$ invariant mass distribution), but the background contribution remained large ($\sim$34%). The $f_0(1370)(\pi\pi)_S$ hypothesis gave also an improvement of the fit and in addition it reduced the background contribution to a reasonable value ($\sim$21%). Moreover, the $K\bar{K}\pi\pi \rightarrow f_0(1370)(\pi\pi)_S$ amplitude contribution produced a peak around 1.68 GeV and could therefore be interpreted as the production of a resonant state of such a mass and with a width of about 0.250 GeV or more.

Table 1
Fractional contributions to the best fitting amplitude for the full data sample. $\mathcal{L}$, χ^2/N and N_{ev} are given also for the reduced data sample.

$p\bar{p}$ init. state	Amplitude		Intensity (%)
$^1S_0$	$\eta(1400)\pi^+\pi^-$	$(a_0\pi)(\pi\pi)$	2.0 $\pm$ 0.4
		$(K^*\bar{K}+c.c.)(\pi\pi)$	3.5 $\pm$ 0.4
		$(K\bar{K}\pi^0)(\pi\pi)$	10.5 $\pm$ 1.4
	$\eta(1460)\pi^+\pi^-$	$(K^*\bar{K}+c.c.)(\pi\pi)$	2.3 $\pm$ 0.8
	$\eta f_0(1370)$	$(\pi^+\pi^-\pi^0)(K^+K^-)$	4.2 $\pm$ 0.5
	$f_0(1710)\pi^0$	$(K^+K^-\pi^+\pi^-)\pi^0$	0.5 $\pm$ 0.5
	$K^*\bar{K}^*\pi^0$	$(K^+\pi^-)(K^-\pi^+)\pi^0$	0.5 $\pm$ 0.2
$^3S_1$	$\omega f_0(1370)$	$(\pi^+\pi^-\pi^0)(K^+K^-)$	28.5 $\pm$ 1.5
$^1P_1$	$\eta\phi$	$(\pi^+\pi^-\pi^0)(K^+K^-)$	4.6 $\pm$ 0.2
$^3P_1$	$\eta f_0(1370)$	$(\pi^+\pi^-\pi^0)(K^+K^-)$	8.8 $\pm$ 0.3
	$f_1(1420)\pi^+\pi^-$	$(K^*\bar{K}+c.c.)(\pi\pi)$	2.0 $\pm$ 0.3
	K^* dir. prod.	$(K^*\bar{K}+c.c.)(\pi\pi)$	2.0 $\pm$ 0.8
	$K^{*0}\bar{K}^{*0}\pi^0$	$(K^+\pi^-)(K^-\pi^+)\pi^0$	1.1 $\pm$ 0.4
	$f_0(1710)\pi^0$	$(K^+K^-\pi^+\pi^-)\pi^0$	14.5 $\pm$ 0.5
Bkg			15.0 $\pm$ 2.0
-$\mathcal{L}$	12138		2397
χ^2/N_{DOF}	1.236 ($N_{DOF}=1250$)		1.056 ($N_{DOF}=1126$)
Nr. events	8598		3641

All other hypotheses used for the description of the $K\bar{K}\pi\pi$ system were characterised by a larger background contribution ($>36\%$) and no reasonable improvement of the fit quality.

The final form of the fitting amplitude was then constructed by including the contribution of direct $K^{*0}\bar{K}^{*0}\pi^0$ final state and the production of a scalar resonant state ($f_0(1710)$) decaying into $(K\bar{K})_S(\pi\pi)_S$, where the $(K\bar{K})_S$ system was parameterised in terms of a Breit-Wigner amplitude, here called $f_0(1370)$.

The results of the best fit are shown in Table 1 for both the reduced and the full data samples. For the latter, the best fit solution (with 17 free parameters) yields $\mathcal{L}=-12138$, $\chi^2/N_{DOF}=1545/1250$ and a background contribution of $\sim$15%. The resonant state observed for the first time in the $K\bar{K}\pi\pi$ system

Table 2

Tests of spin assignment and decay modes of $f_J(1710)$ over the reduced data sample. The last four columns include a constant coherent $K^*\bar{K}^*$ production term.

$f_2(1710) \to (K\pi)(K\pi)$	-	×	-	-	-	-	×	-	-	-
$f_2(1710) \to f_0(1370)(\pi\pi)$	-	-	×	-	-	-	-	×	-	-
$f_0(1710) \to (K\pi)(K\pi)$	-	-	-	×	-	-	-	-	×	-
$f_0(1710) \to f_0(1370)(\pi\pi)$	-	-	-	-	×	-	-	-	-	×
$\to K^*\bar{K}^*$	-	-	-	-	-	×	×	×	×	×
Bkg. (%)	40.7	40.5	41.	36.	21.	34.	34.	34.	28.	26.
$-\mathcal{L}$	2220.	2222.	2226.	2227.	2302.	2334.	2336.	2337.	2354.	2390.
$\chi^2/N_{DOF}(N_{DOF} = 1126)$	1.291	1.288	1.240	1.267	1.179	1.145	1.146	1.141	1.076	1.061
N_P	12.	15.	15.	14.	14.	15.	18.	18.	17.	17.

can tentatively be identified with another decay mode of the $f_0(1710)$ [9].

The results of tests of spin assignement and decay modes of the $f_J(1710)$ are shown in Table 2 for the reduced data sample. The $f_0(1710)$ mass and width used in these fits were 1.670 ± 0.02 GeV and 0.267 ± 0.036 GeV, respectively. The $J = 2$ assignment for the spin of the $K\bar{K}\pi\pi$ resonance was tested using resonance parameters from the analysis of J/Ψ radiative decays to K^+K^- from the BES Collaboration [12]. The fit with the 2^{++} hypothesis has an additional parameter since 2^{++} is also allowed from $\bar{p}p\ ^3P_2$ initial state. The result of this fit turned out of poorer quality if compared to that where the spin assignement is 0. It determined a decreasing of the likelihood value, an increase of the χ^2 and a greater background contribution (see last four columns of Table 2, where a constant coherent $K^*\bar{K}^*$ production term is included). From the table it comes out also that the most probable decay mode of the $f_0(1710)$ is $f_0(1370)(\pi\pi)$.

Alternative ways for suppressing the large incoherent background and a search for contributions from other intermediate states were attempted with negative results. Indeed, neither an improvement of the quality of the fit nor a reduction of the background were observed when $\bar{p}p \to \phi(1680)\pi^0$, $h_1(1380)(\pi\pi)$, $f_1(1510)(\pi\pi)$ channels were considered.

The $f_0(1710)$ resonance is dominantly produced from the $^3P_1$ initial state (with relative L=1) and it is practically absent from $^1S_0$ (relative L=0). Such a 'centrifugal barrier anomaly' was also observed in $\bar{p}p \to \phi\pi^0$ annihilations at rest [13,14] since this channel is mostly produced from the triplet S wave ($^3S_1$) with relative L=1, and unobserved from initial $^1P_1$ with relative L=0.

3.2 Partial wave analysis

The resonance contributions to the best fitting amplitude, and in particular the presence of a strong interfering $K^+K^-\pi^+\pi^-$ wave from $^3P_1$ were checked by making a partial wave analysis (PWA) of the $K^+K^-\pi^0$ system. To perform such an analysis it was necessary to simplify the structure of the fitting

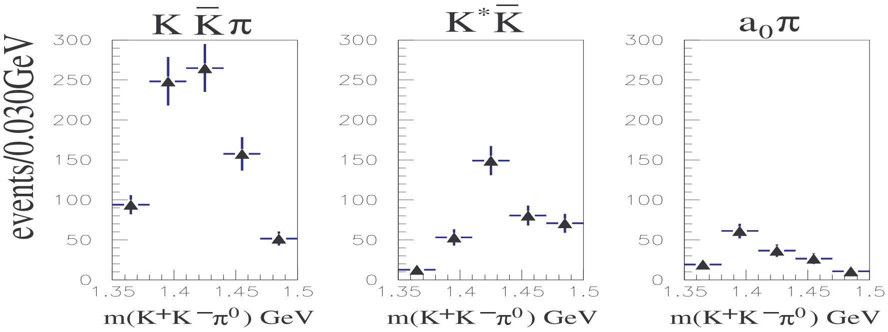

Fig. 5. $K^+K^-\pi^0$ *intensity spectra from the partial wave analysis of* $^1S_0$ *initial protonium wave.*

amplitude. All Breit-Wigner factors entering in the amplitude expression were removed. The considered partial amplitudes were those describing the $K\bar{K}\pi$ isobar decaying into $a_0\pi$, $K^*\bar{K} + c.c.$, as well as directly into $K\bar{K}\pi$ from $^1S_0$ initial state, and into $K^*\bar{K} + c.c.$ from initial $^3P_1$. In the $^3P_1$ amplitude an isobar $K\bar{K}\pi\pi$ decaying into $f_0(1370)(\pi\pi)_S$ was also considered and, in order to arrive to a stable solution, the phase space incoherent background contribution was fixed to the value obtained from the global fit. Due to several relatively small contributions which were neglected in this type of analysis, the relative phases between partial waves were not well defined and only the intensity distributions of different partial waves were analysed.

The general trend of partial wave intensities agreed well with the results of the global fit. All partial waves from $\bar{p}p$ $^1S_0$ showed a resonant peak around 1.41 GeV, the $\eta(1400)$ (see Fig. 5). The intensity of $K^*\bar{K} + c.c.$ from this wave, besides the peak at 1.41 GeV, showed an asymmetry at higher mass suggesting the presence of the second pseudoscalar $\eta(1460)$.

From the initial $^3P_1$ wave, the resonant peak of $f_1(1420)$ is shifted to 1.45 GeV due to the interference between the $K^+K^-\pi^+\pi^-$ amplitude and the $K^*\bar{K}$ system from $K^+K^-\pi^0$, a behaviour well seen from the $^3P_1$ projection of the global fit amplitude, as shown in Fig. 6. In the figure, the superposition of the $^1S_0$and $^3P_1$ partial waves intensities to the global fit results is also shown.

3.3 Global best fits

In a final series of fits a search for a possible $f_1(1285)$ signal, as well as an investigation of the sensitivity of the data to the existence of the $f_1(1420)$ and of the second pseudoscalar, the $\eta(1460)$, were performed.

After a preliminary grid search for a better determination of the masses and widths of the resonances produced in the reaction, a search for the optimal

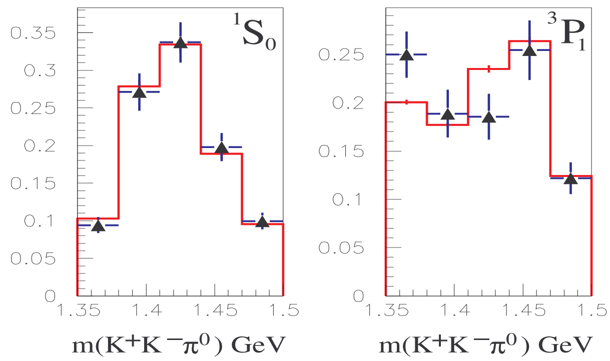

Fig. 6. *Superposition of the ${}^1S_0$ and ${}^3P_1$ partial waves intensities to the global fit results. The distributions were arbitrarely normalized to unity.*

number of free parameters (the absolute value and the relative phase of partial amplitudes) suitable to describe the data was performed. Starting with 21 free parameters, those parameters which were compatible with zero were switched off, one by one. The number of free parameters was thus reduced to 15 (9 real coefficients and 2 relative phases, 3 relative initial state contributions and one additional parameter to describe the background contribution), with no negative effect on the quality of the fit.

Although not directly observed in the $K^+K^-\pi^0$ invariant mass distribution of the reduced data sample, the presence of the $f_1(1285)$ could be demonstrated if some selection criteria on the K^+K^- invariant mass (< 1.052 GeV) and $\pi^+\pi^-$ invariant mass (> 0.41 GeV) were applied. Such criteria intended to emphasise the a_0 production and to select the kinematical region of low $K^+K^-\pi^0$ invariant mass. The resulting invariant mass distributions are shown in Fig. 7. The curve superimposed to the data of Fig. 7a is the result of best fit solution neglecting the contribution of the $f_1(1285)$. An evident better agreement with the experimental data is visible in Fig. 7b, where the contribution of the $f_1(1285)$ from $P-$wave was added to the best fitting amplitude.

The results of the tests of the sensitivity of data to the existence of the axial vector $f_1(1420)$ are reported in Table 3. The tests were performed by removing the $f_1(1420)$ contribution from the amplitude in order to see whether the direct $K^{*\pm}\bar{K}$ production or some interference effect could reproduce the best solution. The first line of the table reports the results of the fit including both contributions; lines 2 and 3 show the results when $K^*\bar{K}$ direct production or $f_1(1420)$ respectively were excluded. Finally, the last line is the best fit solution were some parameters compatible with zero were switched off.

The results of the tests of the sensitivity of data to the presence of the $\eta(1460)$ are presented in Table 4. By removing the $\eta(1460)$ from the fitting amplitude, and keeping fixed the parameters of all other resonances, the quality of the fit became worse (second line). However, if masses and widths of $\eta(1400)$ and

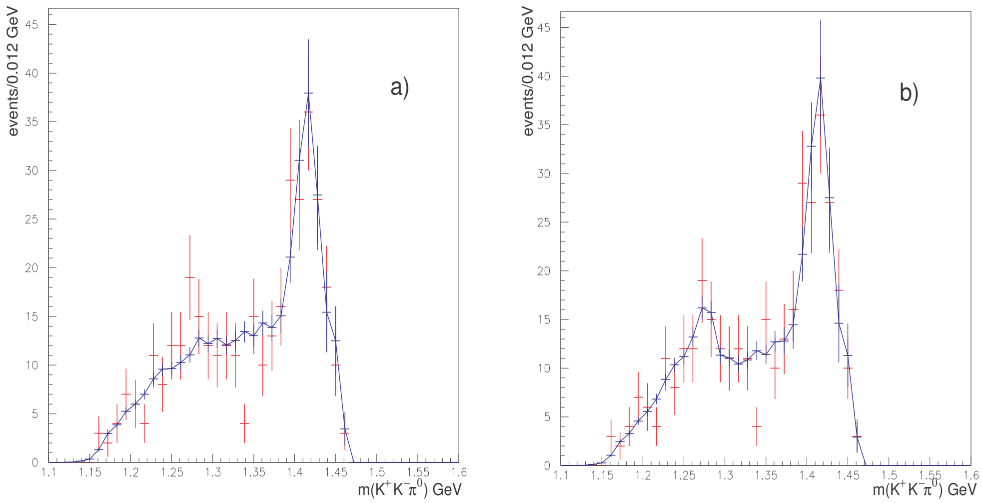

Fig. 7. *$K^+K^-\pi^0$ invariant mass spectrum with selection criteria applied to $m(K^+K^-)$ and $m(\pi^+\pi^-)$, as described in the text. The lines superimposed to the experimental points are best fit solutions without (a) and with (b) including the $f_1(1285)$ in the amplitude.*

Table 3
Tests of sensitivity to the $f_1(1420)$ over the reduced data sample.

-$\mathcal{L}$	$\chi^2/N_{DOF}(N_{DOF} = 1126)$	$(K^+K^-\pi^0) \to K^*\bar{K} + c.c.$ %	$(K^+K^-\pi^0) \to f_1(1420)$ %	N_P
2413.6	1.057	1.6	2.5	21
2406.8	1.064	-	5.3	19
2391.4	1.078	6.8	-	19
2397.0	1.056	2.6	3.2	15

Table 4
Tests of sensitivity to the $\eta(1460)$ over the reduced data sample.

$\eta(1400)$ % $(a_0\pi)$	$\eta(1400)$ % $(K^*\bar{K})$	$\eta(1400)$ % $(K^+K^-\pi^0)$	$\eta(1460)$ % $(K^*\bar{K})$	$f_1(1420)$ % $(K^*\bar{K})$	-$\mathcal{L}$	χ^2/N_{DOF}
3.2	4.05 (M = 1.413 Γ = 0.052)	17.6	3.8 (M = 1.461 Γ = 0.120)	3.2 (M = 1.420 Γ = 0.061)	2397.0	1.056
4.4	7.20 (M = 1.413 Γ = 0.052)	15.3	- -	3.7 (M = 1.420 Γ = 0.061)	2366.7	1.083
3.3	7.80 (M = 1.415 Γ = 0.068)	15.8	- -	4.2 (M = 1.419 Γ = 0.162)	2393.7	1.050

$f_1(1420)$ were left free, an equally good description of the data was obtained (last line). The price paid for that is a very large width for the axial vector $f_1(1420)$, in contradiction with the previous OBELIX results [5] and with all the values reported in literature [9]. From these tests one can conclude that the present data are sensitive to the presence of a second pseudoscalar in the

$K\bar{K}\pi$ system, at a mass around 1.46 GeV, decaying mainly into $K^*\bar{K} + c.c.$, in agreement with the previous results of the OBELIX Collaboration [4,5] and with the earlier analyses performed by Mark III [15] and DM2 [16].

The above tests for the significance of the $f_1(1420)$ and $\eta(1460)$, were done using the reduced data sample (without the contributions of η and ω). However, they were repeated using the full data sample and the two sets of results were found in excellent agreement.

4 Conclusions

From the analysis of a sample of $\bar{p}p$ annihilations at rest in gaseous H_2 at NTP into the $K^+K^-\pi^+\pi^-\pi^0$ final state the following evidences can be drawn. In the $K^+K^-\pi^0$ system it is required the presence of two pseudoscalar states: the first with $m = 1.413 \pm 0.002$ GeV, $\Gamma = 0.051 \pm 0.004$ GeV; the second with $m = 1.460 \pm 0.012$ GeV, $\Gamma = 0.120 \pm 0.015$ GeV; and of one axial vector state with $m = 1.420 \pm 0.003$ GeV, $\Gamma = 0.061 \pm 0.005$ GeV. The presence of a second axial vector state, the $f_1(1285)$, was also demonstrated. These results are in agreement with the OBELIX previous analyses on the $K^{\pm}K^0\pi^{\mp}\pi^+\pi^-$ system [4–6]. In addition, in the $K^+K^-\pi^+\pi^-$ system, an evidence for a scalar state with $m = 1.670 \pm 0.020$ GeV, $\Gamma = 0.267 \pm 0.035$ GeV, was found.

It was therefore confirmed once more that the pseudoscalar state named $\eta(1440)$ in the PDG [9] is indeed the superposition of two independent states, the $\eta(1400)$ and the $\eta(1460)$, with different decay modes. According to the most recent interpretations [17], the higher mass state is likely to be the $s\bar{s}$ member of the radially excited pseudoscalar nonet, whereas the lower mass state should be an exotic, under the hypothesis that the $\eta(1295)$ is the non-strange member of the excited pseudoscalar nonet. The $\eta(1400)$ has strong affinity for glue, and its properties and mass are even consistent with those expected for a bound state of light gluinos [18].

The scalar resonance found in the $K^+K^-\pi^+\pi^-$ system could be identified with another decay mode of the $f_0(1710)$, although the width found here ($\Gamma = 0.267$ GeV)is somewhat larger. Its nature has not yet been established and interpretations ranging from glueball to molecular state were suggested [9,10] The decay mode of the $f_0(1710)$ in the $K\bar{K}\pi\pi$ final state was predicted in ref. [19] and [20], in the framework of $K^*\bar{K}^*$ bound states or vector-meson molecules, both models giving the $K^*\bar{K}^*$ as the dominant isobar composition of this final state. Although a resonant behaviour of the $K^*\bar{K}^*$ system cannot be excluded, this contribution turned out in the present analysis to be very small, in agreement with the central production of $K^*\bar{K}^*$ from the WA76 experiment [21], in which the $K^*\bar{K}^*$ contribution was interpreted as a non-resonant threshold enhancement. In this work, the dominant isobar decomposition of the $K\bar{K}\pi\pi$ decay mode of the $f_0(1710)$ turned out $f_0(1370)(\pi\pi)_S$, where $f_0(1370)$ is a broad $K\bar{K}$ scalar state with mass 1.399 ± 0.010 GeV and width 0.197 ± 0.030 GeV.

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