A FURTHER STUDY OF THE CENTRALLY PRODUCED $\pi^+\pi^-$ AND $\pi^+\pi^-\pi^+\pi^-$ CHANNELS IN pp INTERACTIONS AT 300 AND 450 GEV/C

Presented by A. Kirk, CERN
The WA91 Collaboration

G. Vassiliadis
Athens University, Nuclear Physics Department, Athens, Greece

D. Di Bari, D. Elia, R. Fini, B. Ghidini, V. Lenti, R.A. Loconsole, V. Manzari, F. Navach
Dipartimento di Fisica dell'Università and Sezione INFN, Bari, Italy

A. Bayes, J.N. Carney, S. Clewer, J.P. Davies, C.J. Dodenhoff, D. Evans, J.B. Kinson, K. Norman, O. Villalobos Baillie, M.F. Votruba
University of Birmingham, Physics Department, Birmingham, U.K.

F. Antinori, D. Barberis, W. Beusch, F.R. French, A. Jacholkowski, A. Kirk, P. Martinengo, E. Quercigh, M. Sené, R. Sené
CERN, European Organization for Nuclear Research, Geneva, Switzerland

Y. Kulchitsky, S. Maljukov, I. Minashvili, V. Romanovsky, N. Russakovich, A. Semenov, A. Solovjev, G. Tchlatchidze
JINR, Dubna, Russia

An analysis of the centrally produced $\pi^+\pi^-$ and $\pi^+\pi^-\pi^+\pi^-$ mass spectra from the WA76 and WA91 experiments is presented, which shows that in the $\pi^+\pi^-\pi^+\pi^-$ channel there are two new states, the $f_0(1450)$ and $f_2(1900)$. There is another new state in the $\pi^+\pi^-$ channel with $M = 1497 \pm 30$ MeV and $\Gamma = 199 \pm 30$ MeV, which is compatible with the $f_0(1520)$ observed by the Crystal Barrel experiment. Another interpretation is discussed, where the 1450 and 1497 GeV structures are explained as being due to an interference effect between the $f_0(1365)$ and $f_0(1520)$.

1 Introduction

The WA76 collaboration reported the observation of two previously unobserved mesons, which it called the X(1450) and X(1900), decaying to $\pi^+\pi^-\pi^+\pi^-$ in the reaction

$$pp \rightarrow p_f(\pi^+\pi^-\pi^+\pi^-)p_s \tag{1}$$

at 300 GeV/c [1], where the subscripts f and s indicate the fastest and slowest particles in the laboratory respectively. In contrast, no clear evidence was seen for the X(1450) or X(1900) in the 85 GeV/c data of the same experiment [2]. The increase in cross section with increased incident energy [1] is consistent with the formation of these states via a double Pomeron exchange mechanism, which is predicted to be a source of gluonic states [3]. It is interesting to note that the X(1450) state has not been observed in any other production mechanism.

The WA91 experiment [4], which studied reaction (1) at 450 GeV/c, confirmed the existence of these states and, from a spin analysis, showed that the X(1450) has $I^G J^{PC} = 0^+0^{++}$ and the X(1900) has $I^G J^{PC} = 0^+2^{++}$; hence they should be called the $f_0(1450)$ and $f_2(1900)$ respectively.

The WA76 collaboration has also published an analysis of the centrally produced $\pi^+\pi^-$ channel [5] in which it showed that, in order to fit the $\pi^+\pi^-$ mass spectrum above the $f_2(1270)$ they needed to introduce a Breit-Wigner with a mass of 1472 ± 12 MeV and a width of 195 ± 30 MeV interfering with the background. This state is similar in mass and width to the $f_0(1520)$ observed by the Crystal Barrel experiment at LEAR [6]. In addition to this state the Crystal Barrel experiment also observed another scalar with a mass of 1365 ± 35 MeV and width 270 ± 70MeV, called the $f_0(1365)$. A recent reanalysis [7] of the $\pi^+\pi^-\pi^+\pi^-$ channel produced in radiative J/ψ decay has shown that the mass spectrum can be described in terms of these resonances and it is possible that the $f_0(1450)$ observed in the $\pi^+\pi^-\pi^+\pi^-$ mass spectrum in central production could also be due to an interference effect between these two states.

This paper presents the combined WA76 and WA91 data on the $\pi^+\pi^-\pi^+\pi^-$ and $\pi^+\pi^-$ final states and discusses possible interpretations of these final states in the light of the Crystal Barrel results mentioned above.

2 Analysis of the reaction $pp \to p_f(\pi^+\pi^-\pi^+\pi^-)p_s$

The data come from experiments WA76 and WA91 which have been performed using the CERN Omega Spectrometer. Details of the layout of the apparatus, the trigger conditions and the data processing have been given in previous publications [8]. The selection of reaction (1) has been given in ref. [1] for the WA76 experiment and ref. [4] for the WA91 experiment.

The $\pi^+\pi^-\pi^+\pi^-$ effective mass spectra from experiments WA76 [1] and WA91 [4] look very similar and the combined spectrum is shown in fig. 1a. In order to describe the $\pi^+\pi^-\pi^+\pi^-$ combined mass spectrum, it has been fitted using three Breit-Wigners representing the $f_1(1285)$, the $f_0(1450)$ and $f_2(1900)$ plus a background of the form $a(m - m_{th})^b exp(-cm - dm^2)$, where m is the $\pi^+\pi^-\pi^+\pi^-$ mass, m_{th} is the $\pi^+\pi^-\pi^+\pi^-$ threshold mass and a, b, c, d are fit parameters. Reflections from the $\eta\pi^+\pi^-$ decay of the η' and $f_1(1285)$ give small enhancements in the $\pi^+\pi^-\pi^+\pi^-$ mass spectrum in the 0.8 and 1.1 GeV

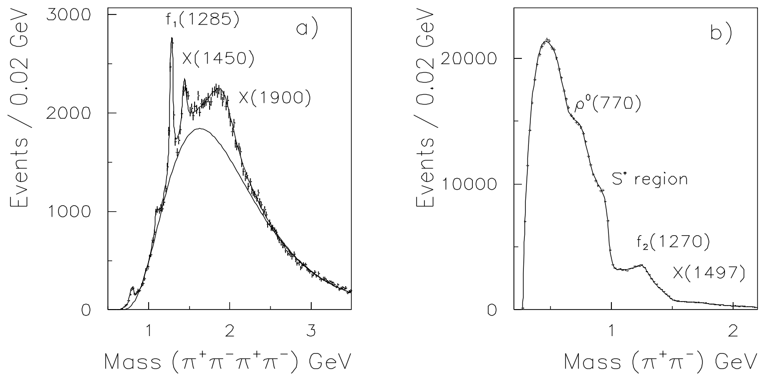

Figure 1: a) The $\pi^+\pi^-\pi^+\pi^-$ and b) the $\pi^+\pi^-$ mass spectram with fits described in the text.

regions due to a slow π^0 from the decay of an η falling within the missing momentum cuts. In order to get a correct description of the $\pi^+\pi^-\pi^+\pi^-$ mass spectrum two histograms representing a Monte Carlo simulation of each reflection have been included in the fit. The masses and widths determined from the fit are given in table 1.

A spin-parity analysis of the $\pi^+\pi^-\pi^+\pi^-$ channel has been performed using an isobar model [4]. Different combinations of waves and isobars have been tried and insignificant contributions have been removed from the final fit. The results of the best fit are shown in fig. 2 for the combined WA76 and the WA91 data. Superimposed on the figures are the resonance contributions coming from a fit to the mass spectrum in 40 MeV bins. As can be seen, the $J^P = 1^+\ \rho(\pi\pi)_{Pwave}$ clearly describes the $f_1(1285)$ in size and shape (fig. 2a) and the $J^P = 0^+\rho(\pi\pi)_{Pwave}$ distribution shows the $f_0(1450)$ peak on top of a broad enhancement (fig. 2b).

The $f_2(1900)$ is described by the sum of the neither the $J^P = 2^+\ a_2(1320)\pi$ and $J^P = 2^+\ f_2(1270)(\pi\pi)_{Swave}$ (fig. 2c).

3 Analysis of the reaction $pp \to p_f(\pi^+\pi^-)p_s$

Fig. 1b shows the combined WA76 and WA91 $\pi^+\pi^-$ mass spectrum. It has been fitted using the parametrisation described in ref. [5]. In order to fit the region on the high mass side of the $f_2(1270)$ a Breit-Wigner interfering with

Table 1: Parameters of resonances in the fit to the $\pi^+\pi^-\pi^+\pi^-$ mass spectrum

	Mass (MeV)	Width (MeV)	Observed decay mode	$I(J^{PC})$
$f_1(1285)$	1280 ± 2	36 ± 5	$\rho\pi\pi$	$0(1^{++})$
$f_0(1450)$	1445 ± 5	65 ± 10	$\rho\pi\pi$	$0(0^{++})$
$f_2(1900)$	1918 ± 12	390 ± 60	$a_2(1320)\pi$ $f_2(1270)\pi\pi$	$0(2^{++})$

the background has been introduced. The mass and width are found to be

$$\mathrm{M} = 1497 \pm 30 \quad \mathrm{MeV} \qquad \Gamma = 199 \pm 30 \ \ \mathrm{MeV}$$

It is not possible to fit this region using the parameters of the $f_0(1450)$. Therefore, from the WA76 and WA91 data we conclude that there are two separate resonances, one in the $\pi^+\pi^-\pi^+\pi^-$ channel and a second in the $\pi^+\pi^-$ channel.

4 A comparison with the states observed in the Crystal Barrel experiment

After the WA76 and WA91 data were published, the results from the Crystal Barrel experiment have become available. Therefore we now investigate whether the data from WA76 and WA91 can be described using the $f_0(1365)$ and $f_0(1520)$ observed in the Crystal Barrel experiment. It is clear that the mass and width of the state required to fit our $\pi^+\pi^-$ spectrum are close to those of the $f_0(1520)$, but this state on its own can not explain the narrow peak observed in our $\pi^+\pi^-\pi^+\pi^-$ channel.

Since the $f_0(1365)$ and $f_0(1520)$ have the same quantum numbers they can interfere and top possibility is that the effects observed in the $\pi^+\pi^-$ and $\pi^+\pi^-\pi^+\pi^-$ channels in central production could be produced by these two states interfering with each other and also with an S-wave background. In

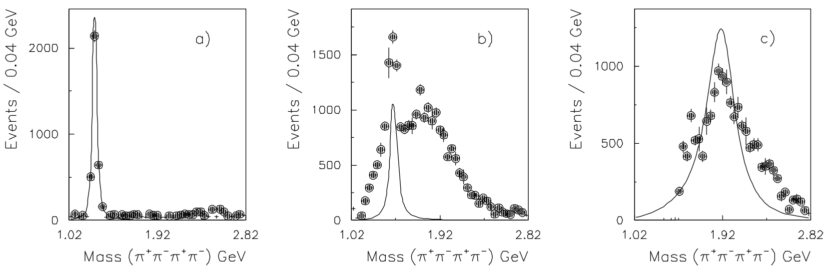

Figure 2: Results of the spin parity analysis for the combined WA76 and WA91 data: a) 1^+ $\rho(\pi\pi)_{Pwave}$, b) 0^+ $\rho(\pi\pi)_{Pwave}$ and c) sum of 2^+ $a_2(1320)\pi$ and 2^+ $f_2(1270)(\pi\pi)_{Swave}$. The superimposed curve is the resonance contribution coming from a fit to the mass spectrum.

order to test this hypothesis an attempt has been made to try to create the narrow peak observed in the $\pi^+\pi^-\pi^+\pi^-$ channel using an expression of the form

$$B_{X(1450)}(m) = |A_{f_0(1365)}BW_{f_0(1360)} + A_{f_0(1520)}BW_{f_0(1520)}e^{i\delta}|^2 \qquad (2)$$

where the A_f determine the relative amplitudes of the two Breit-Wigners, BW_f are Breit-Wigner amplitudes and δ is a mass independent phase between the two states. In order to make the shape of this function describe the $f_0(1450)$ the mass and width of each resonance was allowed to change by up to one standard deviation from their published values and their relative amplitudes and phase were varied. The solid line in fig. 3a shows the Breit-Wigner function used to fit the $\pi^+\pi^-\pi^+\pi^-$ spectrum and the dashed line shows the best curve resulting from interfering the two Crystal Barrel states. The resulting parameters are

$f_0(1365)$	M = 1395	MeV	Γ = 200	MeV	A = 1.0
$f_0(1520)$	M = 1495	MeV	Γ = 125	MeV	A = 0.8

$$\delta = 180^0$$

The agreement is not perfect but the shapes are similar and it must be remembered that in addition to the $J^{PC} = 0^{++}$ resonances there is also a 0^{++} background. As can be seen from fig. 2b there is a background in the

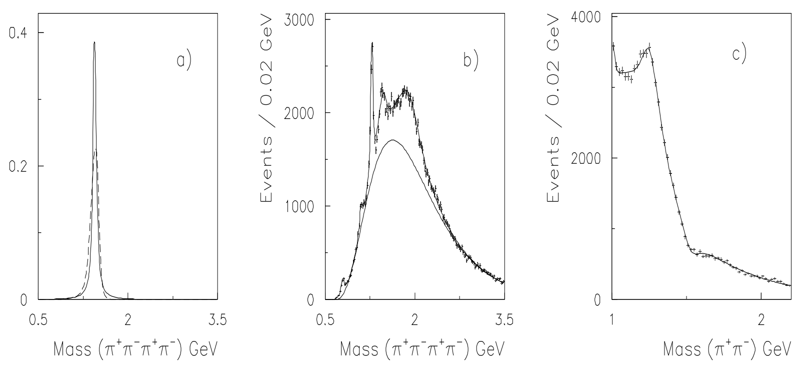

Figure 3: Results obtained using the interference term in equation (2). a) and b) for the $\pi^+\pi^-\pi^+\pi^-$ channel and c) for the $\pi^+\pi^-$ channel with fits described in the text.

$J^P = 0^+\rho(\pi\pi)_{Pwave}$ distribution which could easily interfere with the resonances. However the $J^P = 0^+\rho(\pi\pi)_{Pwave}$ background is not the only 0^+ background possible. Therefore it is not meaningful to try to interfere the two resonances with a background since the shape of that background is arbitrary; hence it will always be possible to choose a background shape that would allow the observed $f_0(1450)$ peak to be fitted. Fig. 3b shows a fit to the total $\pi^+\pi^-\pi^+\pi^-$ mass spectrum using this interference term.

If the same parameterisation is used to fit the $\pi^+\pi^-$ channel, that is, using the two Crystal Barrel states with parameters as given above and allowing interference with the background which is assumed to be S-wave a poor fit results. If the amplitude of the two states is allowed to vary but the phase angle is kept constant at 180^0 then the resulting fit is acceptable but the amount of the $f_0(1365)$ required in the fit is very small, only 0.3 % of the $f_0(1520)$. If the phase angle between the $f_0(1365)$ and the $f_0(1520)$ is left free the fit shown in fig. 3c results. This is again an acceptable fit and the ratio of $f_0(1520)$ to $f_0(1365)$ is now two to one. However the phase angle between the $f_0(1365)$ and $f_0(1520)$ is now 90^0.

5 Conclusions

In summary, in the centrally produced $\pi^+\pi^-\pi^+\pi^-$ mass spectrum two new structures are observed at 1.45 and 1.9 GeV. The peak observed at 1.9 GeV, called the $f_2(1900)$, appears as a broad enhancement in the mass spectrum and decays to $a_2(1320)\pi$ and $f_2(1270)\pi\pi$ with $J^{PC} = 2^{++}$.

There are two interpretations which could explain the 1.45 GeV mass region. Based on centrally produced data alone we would conclude that in the $\pi^+\pi^-\pi^+\pi^-$ channel there is a single resonance, called the $f_0(1450)$, which is a narrow state with $I(J^{PC}) = 0(0^{++})$. There is also another state in the $\pi^+\pi^-$ channel with $M = 1497 \pm 30$ MeV and $\Gamma = 199 \pm 30$ MeV, which is compatible with the $f_0(1520)$ observed by the Crystal Barrel experiment.

The second interpretation based on the two states observed in the Crystal Barrel experiment, the $f_0(1365)$ and $f_0(1520)$, is that the peak observed in the $\pi^+\pi^-\pi^+\pi^-$ channel is due to an interference effect between these two states and that a similar effect is observed in the $\pi^+\pi^-$ channel.

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