**STUDY OF THE $K^+ K^- \pi^+ \pi^-$ SYSTEM CENTRALLY
PRODUCED
IN THE REACTIONS $\pi^+ p \rightarrow \pi^+ (K^+ K^- \pi^+ \pi^-) p$
AND
 $p p \rightarrow p (K^+ K^- \pi^+ \pi^-) p$ at 85 GeV/c**

WA76 Collaboration

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Abstract

The reactions $\pi^+ p \rightarrow \pi^+ (K^+ K^- \pi^+ \pi^-) p$ and $p p \rightarrow p (K^+ K^- \pi^+ \pi^-) p$ where the $(K^+ K^- \pi^+ \pi^-)$ system is centrally produced have been studied at 85 GeV/c. 48% of the final state proceeds through single or double vector meson resonant production i.e., $K^{*0}(890)$ (37%), ϕ (4%), ρ^0 (7%). Evidence is found for associated $K^{*0}(890) \bar{K}^{*0}(890)$ production ($6.4 \pm 1.1\%$) with a cross section ten times higher than that found for associated $\phi \phi$ production in the same experiment.

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1. Introduction

Experiment WA76 at CERN was designed to study centrally produced exclusive final states, and searches for signs of new mesonic states. As the centre of mass energy increases Double Pomeron Exchange (DPE) is one of the production mechanisms which is expected to become relatively more important and, if the Pomeron is composed of gluons, DPE can be expected to be a source of gluonium states [1]. Several experiments have been performed in order to explore this possibility [2]. In addition, the study of associated vector meson production has been proposed as a method of searching for $q\bar{q}q\bar{q}$ multiquark states [3].

Data from this experiment have already been presented showing evidence for exclusive production of vector-vector $\phi \phi$ in the $K^+ K^- K^+ K^-$ final state [4]. In this paper we present the results of the analysis of the $K^+ K^- \pi^+ \pi^-$ final state and show evidence for other associated vector-vector production.

2. Data selection

The data come from the WA76 experiment performed at CERN using the Ω spectrometer (fig. 1) in the H1 beam which contains approximately equal numbers of π^+ and protons at 85 GeV/c. Details of the trigger conditions and the data processing have been given in a previous publication [5].

The reactions

$$\pi^+ p \rightarrow \pi^+_f (K^+ K^- \pi^+ \pi^-) p_s \quad (1)$$

and

$$p p \rightarrow p_f (K^+ K^- \pi^+ \pi^-) p_s \quad (2)$$

where the subscripts f and s refer to the fastest and slowest positive particles in the laboratory system, have been isolated from the sample of the events with six outgoing tracks in the final state. The slow

proton, which triggered a 14-slab scintillation counter, was identified by means of the pulse-height momentum correlation as shown in fig. 2. The fast particle was assumed to be of the same nature as the incident beam. The two kaons were identified by using the information from the two Cherenkov counters C1 and C2, i.e. requiring one positive and one negative particle to be identified as a K or K/p. The two remaining tracks were required, if reaching the Cherenkov system, to have a mass assignment compatible with the pion.

Momentum balancing events were selected by requiring $| \text{missing } P_x | < 3.00 \text{ GeV/c}$, $| \text{missing } P_y | < 0.10 \text{ GeV/c}$ and $| \text{missing } P_z | < 0.08 \text{ GeV/c}$.

The Cherenkov information antiselects all the competitive channels except for the $p \bar{p} \pi^+ \pi^-$ final state. In order to separate this contribution we have plotted in fig. 3 the Δ function defined as

$$\Delta = MM^2(\pi^+ p_f p_s) - M^2(K^+ K^- \pi^+ \pi^-).$$

The plot shows a signal around zero corresponding to reactions (1) and (2) with little background. The second peak corresponds to the $p \bar{p} \pi^+ \pi^-$ final state and is well separated from the $K^+ K^- \pi^+ \pi^-$ channel. The selection of the $K^+ K^- \pi^+ \pi^-$ channel has been achieved by requiring $| \Delta | < 2.0 \text{ GeV}^2$.

The final sample consists of 1996 events of which 61% come from the p beam and 39% come from the π^+ beam.

3. Mass spectra

The 4-body, 3-body and 2-body effective mass spectra relevant to the present study are shown in figs 4 and 5. No structure is observed in the mass spectra not shown. Resonance production is observed in the two-body mass distributions, i.e. K^{*0} ($\bar{K}^{*0}$) in the $K^+ \pi^-$ ($K^- \pi^+$) mass combinations, ρ^0 and Δ^{++} in the mass spectra which include the fast track. Evidence for central ϕ and ρ^0 production is also seen.

In order to explore the possibility of associated resonance production, we plot in fig. 6 the scatter diagram of $M(\pi^+ \pi^-)$ vs $M(K^+ K^-)$. No obvious excess of events appears in the region corresponding to associated $\phi \rho^0$ production. Fig. 7 shows the $M(K^- \pi^+)$ vs $M(K^+ \pi^-)$ scatter plot where the K^{*0} bands are clearly visible together with an accumulation of events where the K^{*0} bands overlap.

4. Channel Likelihood Fit

In order to make a quantitative analysis and to separate the different reactions which contribute to the observed final states (1) and (2), we have used the technique of the Channel Likelihood Fit [6] using a modified version of the program CHAFIT [7].

The program performs a maximum likelihood fit of different overlapping amplitudes. We have used Breit-Wigner amplitudes with masses and widths fixed to the Particle Data Group values [8] to describe the observed resonances. Each amplitude has to be normalized by integration over the Lorentz Invariant Phase Space. Our reactions, however, are confined by the trigger conditions to a limited region of phase space and it is difficult to reproduce completely, using standard Monte-Carlo techniques, the phase space distribution in all the mass combinations. All the features of the data were reproduced by generating artificial events where each of the six outgoing tracks was randomly taken from different real events. The events resulting from this kind of Monte-Carlo generator were used as phase space to integrate the input amplitudes for the fit.

The program has been tested with Monte-Carlo data. Phase space events have been used and known amounts of resonances and correlated resonance production have been added. We found that the program was able, within the errors, to correctly reconstruct the given amounts of resonance production. We found also that the size of the errors given by the program was realistic.

The fit has been performed by introducing the amplitudes one at a time in order to observe the likelihood change and verify the sensitivity of the fit to the introduction of a new hypothesis. The various stages of the fit are summarized in table I for the proton data. The introduction of each amplitude generates an increase of the likelihood function for all the single resonance production. We ob-

serve that the introduction of the $\phi \rho^0$ amplitude produces no increase of the likelihood function. A significant increase of the likelihood function is produced, on the other hand, by the introduction of $K^{*0} \bar{K}^{*0}$ associated production. Channels which were found to be consistent with zero amplitude were dropped from the final fit. The results of the fits for both reactions as well as for the sum are shown in table II.

To summarize the results of the fit we find:

- a) no evidence for associated $\phi \rho^0$ production and
- b) evidence for associated $K^{*0} \bar{K}^{*0}$ production at the 5 s.d. level corresponding to 125 ± 25 events.

The quality of the fit has been checked in two different ways:

- a) The fit assigns to each event a probability of belonging to a given final state. Fig. 8 shows the two-body effective mass distributions weighted by their resonant (black area) and non-resonant contributions. It can be seen that the resonant contributions have been satisfactorily taken into account by the fit.
- b) The solution given by the fit has been applied to the Monte-Carlo events and superimposed on the real data in figs 4 and 5; the agreement is satisfactory for all the distributions.

In order to extract information about the $K^{*0}(890) \bar{K} \pi$ effective mass spectrum we have plotted in fig 9a the $K^+ K^- \pi^+ \pi^-$ effective mass spectrum requiring one $K^\pm \pi^\mp$ mass combination to lie in the range (0.83, 0.95 GeV). In order to estimate the background the total $K^\pm \pi^\mp$ mass spectrum has been fitted and the amount of $K^{*0}(890)$ above background falling in the (0.83, 0.95 GeV) mass region has been found to be 55%. The dashed histogram shows the $K^+ K^- \pi^+ \pi^-$ mass spectrum for the events in the K^{*0} side band normalized to 45% background.

The $K^{*0}(890) \bar{K}^{*0}(890)$ mass spectrum has been obtained as follows. Table III shows the event distribution on the $K^- \pi^+$ vs $K^+ \pi^-$ scatter plot of fig. 7 in 9 bins centred around the K^{*0} mass. The $K^{*0} \bar{K}^{*0}$ mass spectrum for the central bin is shown in fig. 9b (solid line). The dashed histogram in the same figure shows the contribution of the wing regions computed (with the symbols of table III) as

$$[2] + [4] + [6] + [8] - [1] - [3] - [7] - [9],$$

where each number refers to the $K^+ K^- \pi^+ \pi^-$ mass spectrum in the appropriate region. The excess of $K^{*0} \bar{K}^{*0}$ events above background is concentrated into a relatively narrow enhancement near threshold.

5. Cross sections

The Feynman x_F distributions for the slow proton, the $K^+ K^- \pi^+ \pi^-$ system and the fast particle are shown in fig. 10. Since no difference has been found in the x_F distribution of the reactions (1) and (2) they have been summed together. The x_F distribution of the $K^+ K^- \pi^+ \pi^-$ system is shifted towards positive values due mainly to the requirement of Cherenkov identification of the two kaons which requires that their momenta be greater than 3.0 GeV/c.

The geometrical acceptance of the apparatus has been computed by Monte-Carlo and used to compute the cross sections in the range $0.0 < x_F < 0.3$. The resulting cross sections are

$$\pi^+ \text{ incident} \quad \sigma(K^+ K^- \pi^+ \pi^-) = 450 \pm 150 \text{ nb}$$

$$\sigma(K^{*0} \bar{K}^{*0}) = 34 \pm 15 \text{ nb};$$

$$p \text{ incident} \quad \sigma(K^+ K^- \pi^+ \pi^-) = 700 \pm 250 \text{ nb}$$

$$\sigma(K^{*0} \bar{K}^{*0}) = 35 \pm 15 \text{ nb}.$$

Since we have already observed associated $\phi \phi$ resonance production in the same experiment [4], it is of interest to compare the relative cross sections. The analysis of the $2K^+ 2K^-$ channel yields cross sections for $\phi \phi$ production in the region $0.0 < x_F < 0.3$ ($\phi \rightarrow K^+ K^-$) of $2 \pm 1 \text{ nb}$ (π^+) and $3 \pm 1 \text{ nb}$ (p). After having corrected for unseen decay modes we obtain a cross section ratio of

$$\sigma(K^{*0} \bar{K}^{*0})/\sigma(\phi \phi) \approx 10$$

in the x_F interval ($0.0 < x_F < 0.3$).

6. Conclusions

We have analyzed the $K^+ K^- \pi^+ \pi^-$ final state centrally produced by incident π^+ and p at 85 GeV/c. 48% of the channel proceeds through single or double vector meson production.

Evidence is found for $\phi \pi^+ \pi^-$ (4%) and $\rho^0 K^+ K^-$ (7%). An important fraction of the channel goes through $K^{*0}(890)$ production (37%). Evidence is found for associated $K^{*0} \bar{K}^{*0}$ (6.4 ± 1.1)% which contrasts with the result found in $\gamma\gamma$ collisions where no associated $K^{*0} \bar{K}^{*0}$ production was seen [9].

A comparison with $\phi \phi$ production in the same x_F range gives a ratio $\sigma(K^{*0} \bar{K}^{*0})/\sigma(\phi \phi) \approx 10$.

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Table captions.

Table I Channel Likelihood Fit of the proton incident data. Errors are shown in brackets.

Table II Results from the Channel Likelihood Fit. Errors are shown in bracket.

Table III Event distribution on the $K^- \pi^+$ vs $K^+ \pi^-$ scatter plot centered around the K^{*0} mass.

Table I

Channel	%	%	%	%	%	%	%	%
$K^0 K^- \pi^+$	24.0 (2.1)	22.6 (2.0)	22.5 (2.0)	22.4 (2.0)	22.3 (2.0)	18.5 (2.1)	18.4 (2.1)	18.9 (2.1)
$\bar{K}^0 K^+ \pi^-$		15.5 (1.9)	15.1 (1.9)	14.9 (1.9)	15.0 (1.8)	11.6 (1.9)	11.6 (1.9)	12.1 (1.9)
$\rho^0 K^+ K^-$			7.3 (2.0)	7.2 (2.0)	7.4 (2.0)	7.5 (2.0)	7.2 (2.0)	7.0 (2.0)
$\varphi \pi^+ \pi^-$				4.1 (0.9)	4.1 (0.9)	4.0 (0.9)	3.6 (1.0)	4.0 (0.9)
Δ^{++}					5.8 (1.5)	5.8 (1.5)	5.8 (1.5)	6.0 (1.5)
$K^0 \bar{K}^0$						5.2 (1.4)	5.2 (1.4)	5.2 (1.4)
$\varphi \rho^0$							0.5 (0.7)	
$K^*(1420)K\pi$								2.7 (1.1)
Phase Sp.	76.0 (2.9)	61.9 (3.0)	55.1 (3.3)	51.5 (3.3)	45.4 (3.5)	47.5 (3.6)	47.8 (3.6)	44.2 (3.7)
Likelihood	8778	8825	8832	8849	8858	8867	8867	8871

T a b l e I I

Channel	p (%)	π^+ (%)	Total
$K^0 K^- \pi^+$	18.9 (2.1)	11.2 (2.5)	16.1 (1.6)
$\bar{K}^0 K^+ \pi^-$	12.1 (1.9)	17.9 (2.6)	14.4 (1.6)
$\rho^0 K^+ K^-$	7.0 (2.0)	7.1 (2.4)	6.9 (1.5)
$\varphi \pi^+ \pi^-$	4.0 (0.9)	3.5 (1.0)	3.7 (0.7)
$K^*(1420)\bar{K}\pi$	2.7 (1.1)	5.3 (1.4)	3.7 (0.8)
$K^0 \bar{K}^0$	5.2 (1.4)	8.5 (1.9)	6.4 (1.1)
Δ^{++}	6.0 (1.5)		
ρ^0_f		6.0 (1.9)	
phase sp.	44.2 (3.7)	40.4 (4.6)	42.5 (2.9)

Figure captions

Fig. 1 Layout of the Ω spectrometer as used in the WA76 experiment.

Fig. 2 Pulse height vs momentum correlation for the slow triggering particle. The dashed line shows the cut used in separating p from π^+ . The rising part of the distribution in the low momentum region is due to protons stopping in the scintillator.

Fig. 3 Δ function distribution.

Fig. 4 Four-body and three-body effective mass distributions. The curves are the results of the fit described in the text. Reactions (1) and (2) have been summed together.

Fig. 5 Two-body effective mass distributions. The curves are the results of the fit described in the text. Reactions (1) and (2) have been summed together.

Fig. 6 Scatter diagram $M(\pi^+ \pi^-)$ vs $M(K^+ K^-)$ for the combined reactions.

Fig. 7 a) Scatter diagram $M(K^- \pi^+)$ vs. $M(K^+ \pi^-)$ for reactions (1) and (2).

b) The same distribution as in a) viewed as a "lego" plot with 20 MeV bin.

Fig. 8 Two body effective mass distributions. The black area represents the resonant contribution as found by the fit.

Fig. 9 a) $K^{*0} \bar{K} \pi$ effective mass distribution. The dashed histogram represents the estimated background.

b) $K^{*0} \bar{K}^{*0}$ effective mass distribution. The dashed histogram represents the estimated background.

Fig.10 Feynman x_F distribution for the slow proton, the central system and the fast particle.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

Fig. 8

Fig. 9

Fig. 10