STUDY OF THE CENTRALLY PRODUCED $K^0_1 K^\pm \pi^\mp$ SYSTEM AT 85 GeV/c

WA76 Collaboration

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Abstract

We have analyzed the $K^0_1 K^\pm \pi^\mp$ system in the reactions $\pi^+ p \rightarrow \pi^+ p (K^0_1 K^\pm \pi^\mp) p$. A spin-parity analysis of the $K^0_1 K^\pm \pi^\mp$ system in the "4C" channel confirms the existence of the 1^{++} E meson which decays mainly through $K^* \bar{K}$. The data allow the presence of a 0^{-+} wave at a level of 14% of the E/ ι signal. The production of D and E mesons in the channels where the $K^0_1 K^\pm \pi^\mp$ system is produced along with a π^0 or $\pi^+ \pi^-$ system is suppressed.

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1. Introduction

One of the basic expectations of the present theory of the strong interactions, QCD, is the existence of hadrons composed of gluons rather than quarks. The search for these new states, the glueballs, has been carried out in several experiments and has led to the discovery of at least two candidates: the ι ($\eta(1440)$) [1] and the θ ($f_2(1720)$) [2]. However, the still undefined situation in the field of light meson spectroscopy makes it difficult to establish them as bona fide glueball states since the possibility that they are 4-quark states or radial excitations cannot be ruled out.

The situation of the ι is confused since this particle is still ambiguous with the E ($f_1(1420)$) meson and whether the two states are the same object or two distinct resonances is still a matter of debate. A review of the status of the so-called E/ι puzzle can be found in ref. [3]. For the present we note the following points:

- a) The E/ι signal found in the radiative J/ψ decay has a mass 20–30 MeV higher and a width $\approx$ 30 MeV larger than the corresponding signal found in hadron interactions.
- b) In the radiative J/ψ decay and $\bar{p} p$ annihilation at rest [4] THE E/ι is found to have $J^{PC} = 0^{-+}$ and the D ($f_1(1285)$) meson is not seen in the mass spectrum. The absence of the D meson (a well established 1^{++} object) may indicate the presence of selection rules.
- c) A recent study [5] of the hadronic J/ψ decay channel $\omega K \bar{K} \pi$ shows a structure whose mass and width are compatible with those of the E meson. A preliminary determination of the spin-parity of such a state gives a result compatible with 1^{++} .
- d) Recently, new results from $\gamma\gamma$ collisions [6] show evidence for a state which is seen only when one of the photons is far off mass shell providing evidence that the spin of the resonance is one. The mass and width of the resonance are found to be consistent with those of the $J^P = 1^+ E$ meson.

The data from the present experiment have already been analyzed and a spin-parity analysis has been performed on the resonances found in the exclusive $K^0, K^\pm \pi^\mp$ system [7]. The results of this

analysis clearly indicate that the spectrum is dominated by two 1^{++} objects: the D and the E mesons. However, recently, new high statistics data have been analyzed on the production of the $K^0, K^\pm \pi^\mp$ system in $\pi^- p$ and $\bar{p} p$ interactions [8] and the results from this analysis are different from ours. They find that the E meson is not a 1^{++} state but rather a 0^{-+} state having the same quantum numbers as the ρ so that the two states can be the same object [9]. In order to obtain this result it is necessary to introduce an interference between different G -parity states in such a way that the final result of their analysis is the presence of two different structures in the 0^{-+} and 1^{++} waves.

In order to clarify the situation with respect to our data we have performed a more detailed analysis which we present in this paper together with new information from other channels.

2. Layout of the apparatus

The layout of the Ω spectrometer at CERN used for this experiment is shown in fig. 1 and it was designed in order to enhance the double exchange graphs (double Pomeron, Regge-Pomeron, Regge-Regge) with respect to single Pomeron (diffractive) or single Regge exchange.

The positively charged H1 beam (45% p, 47% π) in the West Area was incident on a 60 cm long hydrogen target and two Cherenkov counters in the beam allowed positive identification of the pions and protons.

The trigger required:

- a) A fast particle defined by a hit in the counter A ($54 \times 60 \text{ cm}^2$) placed after Cherenkov C2, ≥ 1 hit in a single plane of the forward MWPCs T_2 and T_3 and no hit in the beam veto counter A_0 .
- b) A slow particle defined by demanding one hit on any of the fourteen horizontal slabs of the Slow Proton Counter (SPC), ($56 \times 88 \text{ cm}^2$), and ≥ 1 hit on a single plane of the MWPCs situated on one side of the target. In addition, a hit was demanded in the side of the box counter (TS), surrounding the target, which was nearest the SPC.

- c) In order to reduce the backward diffraction or excitation we requested no hit in the other three sides of the box TS counter which was left open at its front end to allow particles produced centrally to escape downstream.
- d) To reduce the forward diffraction or excitation we requested no hit in two counters (DFC) of dimensions $(30 \times 60 \text{ cm}^2)$ which were placed on either side of the beam and just downstream of drift chamber 2 (DC2).
- e) Elastic events were vetoed by demanding a forward multiplicity of ≥ 2 (outside the beam region) in one plane of the "A3" MWPC.
- f) In addition to the above conditions (called a π trigger) a K/p trigger was imposed to select events having a negatively or positively charged kaon or proton by demanding correlated hits in the hodoscopes H_1, H_2 and H_3 along with no correlated light in the appropriate region of the multicell Cherenkov counters C1 and C2. The Cherenkov counters C1 and C2 were filled with freon 114 and CO_2 respectively, resulting in thresholds for $\pi/K/p$ of 2.8/9.8/18.8 GeV/c for C1 and 5.0/17.4/33.0 GeV/c for C2. An air bag was placed inside C1 in the beam region in order to reduce the multiple scattering on the fast track.

3. Selection of the $K^0, K^\pm \pi^\mp$ channel

The reactions

$$\pi^+ p \rightarrow \pi^+ (K^0, K^\pm \pi^\mp) p_s \quad (1)$$

and

$$p p \rightarrow p_f (K^0, K^\pm \pi^\mp) p_s \quad (2)$$

(where the subscripts f and s denote the fastest and slowest particle in the laboratory system) were isolated from the four-prong events which had in addition a reconstructed V^0 .

Events which balanced the momentum within the errors were selected by requiring $|\text{missing } P_x| < 4.00 \text{ GeV}/c$, $|\text{missing } P_y| < 0.16 \text{ GeV}/c$ and $|\text{missing } P_z| < 0.12 \text{ GeV}/c$. The K^0 signal was selected by requiring $0.475 < m(\pi^+ \pi^-) < 0.52 \text{ GeV}$.

Reactions (1) and (2), "4C" events, were selected from the total sample of events with no missing momentum by using energy conservation which required the Δ -function (shown in fig. 2) to be $|\Delta| < 1.5 \text{ GeV}^2$. Here Δ is defined as $\Delta = MM^2(\pi^+ p p) - M^2(K^0_1 K^\pm \pi^\mp)$.

The Cherenkov information was used to provide two samples of events:

- a) One track was identified as K or ambiguous K/p and the other track was required to have a mass assignment compatible with the π .
- b) Two combinations were considered for each event and compatibility of the mass assignment with the Cherenkov information was required for both tracks.

4. Features of the mass spectra

Fig. 3 shows the $K^0_1 K^\pm \pi^\mp$ mass spectrum corresponding to selection a) together with the Dalitz plot in the E/ι region (defined as $1.37 < M(K^0_1 K^\pm \pi^\mp) < 1.49 \text{ GeV}$). There are 3571 events in the mass spectrum and 910 events in the Dalitz plot.

We observe D and E/ι signals with little background and an E/ι Dalitz plot showing well defined K^* patterns with little indication of a $\delta(a_0(980))$ accumulation in the low $K^0_1 K^\pm$ mass region. We notice, however, that the lower side of the Dalitz plot suffers from a depletion due to the Cherenkov identification of the kaon and this has been verified by Monte-Carlo simulation. In order to avoid the use of corrections, we have used the sample b) for the rest of this analysis. In this case the geometrical acceptance is approximately flat over the Dalitz plot of the low mass region of the $K^0_1 K^\pm \pi^\mp$ system. The less restrictive conditions b) result in a larger background in the E/ι region. The mass spectra

for the condition b) are shown in figs 4a (π^+ incident), 4b (p incident) and 4c (total). The total number of events is 7929 (36% belonging to the π^+ beam and 64% belonging to the p beam) of which 6466 enter with one combination and 1463 events enter with two combinations.

The $K \pi$ mass combinations are shown in fig. 5 where clear K^* signals are evident. Fig. 5c shows the scatter diagram $M(K^0, K^\pm \pi^\mp)$ vs $M(K^0, K^\pm)$ where clear accumulations can be seen in the D and E/ι regions. In order to investigate the δ content of the resonances we have projected the scatter plot onto the $K^0, K^\pm$ projection by requiring $M(K \bar{K} \pi) > 1.37$ GeV (dash-dot, D meson region out) and $M(K \bar{K} \pi) > 1.54$ GeV (dotted line, D and E/ι meson region out) (fig. 5d). We observe a threshold enhancement in the $K^0, K^\pm$ spectrum which vanishes almost completely outside the D region.

The Feynman x_F distributions of the slow particle, the $K^0, K^\pm \pi^\mp$ system and the fast particle are shown in fig. 6.

5. The D meson region

We have performed a Dalitz plot analysis of the $K^0, K^\pm \pi^\mp$ mass spectrum by using a standard isobar model. Details of the Dalitz plot analysis formalism can be found in ref. [10]. The validity of the fitting program has been tested by Monte-Carlo simulation. Events were generated according to different spin-parity assignments. Known mixtures of events of different spin-parities were given to the fitting program and it was found that, within the errors, the program was able to disentangle the different amplitudes.

The fit has been performed by requiring $0^{-+}, 1^{++} \delta\pi$ amplitudes, where the δ has been described in terms of the Flatte' formalism [11], and phase space in the mass range (1.25 – 1.32 GeV, 668 events). The fit gives a zero contribution for the 0^{-+} wave and 95 % for the $1^{++} \delta\pi$ wave. The Dalitz plot of the D meson together with the Monte-Carlo simulation performed by using the results of the fit are shown in figs 7a,b. The Monte-Carlo simulation is superimposed on the data in figs 7c,d. The fit reproduces well the features of the D with the given input hypothesis. The results do not change if the

fit is performed in finer bins and can be summarized as follows: the D meson is a $1^{++} \delta\pi$ state and no other wave is required in this mass region. In particular, the fit does not require the presence of a 0^{-+} state, i.e. the $\eta(1275)$ seen in the partial wave analysis of the $\eta \pi \pi$ system [12].

6. The E/ι region

The Dalitz plot distributions for the E/ι region for incident π^+ and p are shown in figs 8a,b. The two plots show similar features with clear K^* bands. Their sum (1752 events) is shown in fig. 8c. It is of interest to compare the experimental Dalitz plot with what is predicted by generating via Monte-Carlo the pure J^{PC} waves used in the present analysis ($0^{-+} \delta\pi$, $K^* \bar{K}$; $1^{++} \delta\pi$, $K^* \bar{K}$, 1^{-+} , 1^{+-}). The Dalitz plots corresponding to these waves are shown in figs 9a to 9f. The plots have been obtained by generating E/ι events according to a Breit – Wigner shape having as parameters the values given in ref. [7]. One can note how similar the shapes of the E/ι Dalitz plots shown in figs 3 and 8 are to the $1^{++} K^* \bar{K}$ wave (fig. 9d). In particular one should note that, in the presence of a large background and of incoherent single K^* production, the $1^{++} K^* \bar{K}$ could easily be confused with suitable amounts of $0^{-+} \delta\pi$ (fig. 9a), $0^{-+} K^* \bar{K}$ (fig. 9b) and $1^{+-} K^* \bar{K}$ (fig. 9f).

We have fitted the Dalitz plot for each of the 40 MeV slices of the mass spectrum. Several amplitudes in various combinations (including the one just mentioned above) have been tried and different starting values were taken for the fit. Full interference was allowed between waves having the same spin – parity. Interference was also allowed between the 1^{++} and $1^{+-} K^* \bar{K}$ waves. The fits have been performed on the two separate reactions (π^+ incident and p incident) and on their sum. The results of the fit are displayed in figs 10a,b (π^+), 10c,d (p) and 11 (sum) and can be summarized as follows:

- a) The $1^{++} (K^* \bar{K})$ is the dominant wave. Almost the full signal can be interpreted as the sum of $1^{++} (K^* \bar{K})$ and phase space.
- b) A small amount of 0^{-+} wave (180 ± 60 events) is required by the fit, mainly in $K^* \bar{K}$.

- c) If we insert a 1^{+-} wave the $1^{++} K^* \bar{K}$ resonant wave is left intact and the 1^{+-} wave shows a smooth structureless behaviour.
- d) All other waves which have been tried have been found to be consistent with zero.

The results of the fit have been used for a Monte-Carlo simulation and are superimposed on the real data in three different bins of the E/t region in figs 12–14. These plots show satisfactory agreement in all the distributions.

7. Geometrical acceptance and cross sections

The geometrical acceptance of the apparatus for the channel under study has been computed by Monte-Carlo simulation of the reactions (1) and (2). The resulting acceptance due to the triggering conditions a), c), d), e) and f) described in sect. 2 are shown in fig. 15 as a function of the $K^0, K^\pm \pi^\mp$ effective mass for the selections a) (full line) and b) (dashed line) described in sect. 3.

By taking into account losses and unseen decay modes we find the following cross sections for the production of the D and the E meson in the Feynman x_F range between -0.3 and 0.3 :

$$\begin{aligned} \pi^+ \text{ beam} \quad \sigma(D) &= 150 \pm 60 \text{ nb}, \\ \sigma(E) &= 410 \pm 150 \text{ nb}, \end{aligned}$$

$$\begin{aligned} p \text{ beam} \quad \sigma(D) &= 290 \pm 110 \text{ nb}, \\ \sigma(E) &= 820 \pm 330 \text{ nb}, \end{aligned}$$

where the error on the cross sections has been increased to take account of the uncertainties of the Monte-Carlo simulation and the estimation of the losses.

8. The $K^0, K^\pm \pi^\mp \pi^0$ channel

We have searched for D and E/ι signals in the reactions

$$\pi^+ p \rightarrow \pi^+ (K^0, K^\pm \pi^\mp \pi^0) p_s \quad (3)$$

and

$$p p \rightarrow p_f (K^0, K^\pm \pi^\mp \pi^0) p_s. \quad (4)$$

The channel has been selected by requiring one reconstructed V^0 , one particle identified as a kaon or ambiguous K/p by using the Cherenkov information, $| \text{missing } P_x | > 4.00 \text{ GeV/c}$ or $| \text{missing } P_y | > 0.16 \text{ GeV/c}$ or $| \text{missing } P_z | > 0.12 \text{ GeV/c}$. The slow particle was identified as a proton by using the pulse-height vs momentum correlation recorded on the slow proton counter. The total missing mass squared (MM^2) is shown in fig. 16a where a clear π^0 peak can be seen over the background.

The "1C" reactions (3) and (4) have been selected by requiring, in addition to the above cuts, that $| MM^2 | < 0.2 \text{ GeV}^2$. The above cut selects 2310 events (35% belonging to the π^+ beam and 65% to the p beam).

The total $K^0, K^\pm \pi^\mp \pi^0$ mass spectrum (not shown) does not show any significant structure. The $K^0, K^\pm \pi^\mp$ mass spectrum is shown in fig. 16b where D and E/ι signals can be seen over a relatively large background and can be compared with fig. 3a where the same mass spectrum is shown for the "4C" channel. The request of having a π^0 in the final state results in smaller D and E/ι signals. By imposing higher momentum cuts on the π^0 we have verified that the observed D and E/ι are not mainly due to contamination coming from the "4C" channel.

In order to have a quantitative estimate of the D and E/ι production in the two channels we have fitted the 4C and 1C mass spectra in the same Feynman x_F range (0. - 0.3). We find

$$\sigma(D)_{1C}/\sigma(D)_{4C} = 0.06 \pm 0.02$$

and

$$\sigma(E/\iota)_{1C}/\sigma(E/\iota)_{4C} = 0.16 \pm 0.04.$$

9. The $K^0_1 K^\pm \pi^\mp \pi^+ \pi^-$ channel

The reactions

$$\pi^+ p \rightarrow \pi^+ f (K^0_1 K^\pm \pi^\mp \pi^+ \pi^-) p_s \quad (5)$$

and

$$p p \rightarrow p_f (K^0_1 K^\pm \pi^\mp \pi^+ \pi^-) p_s \quad (6)$$

have been isolated from the sample of 6-prongs events having one particle identified as a K or ambiguous K/p and a reconstructed V^0 . Events which balanced momentum, within errors, were obtained by requiring $|\text{missing } P_x| < 4.0 \text{ GeV}/c$, $|\text{missing } P_y| < 0.16 \text{ GeV}/c$ and $|\text{missing } P_z| < 0.12 \text{ GeV}/c$. The Δ -function distribution is shown in fig. 17a. A cut of $|\Delta| < 1.5 \text{ GeV}^2$ selects a total of 602 "4C" events (36% and 64% belonging to π^+ and p beams respectively).

The $(\pi^+ \pi^-)$ mass spectrum (two combinations per event) is shown in fig. 17b and does not show structure. The $K^0_1 K^\pm \pi^\mp$ (two combinations per event) mass spectrum is shown in fig. 17c. No clear indication of signals in the D and E/ι regions is seen. The dashed histogram represents the doubly charged combinations $K^0_1 K^+ \pi^+$ and $K^0_1 K^- \pi^-$.

10. Conclusions

To summarize the results of this analysis, we find:

- a) Parametrizing the threshold S-wave enhancement in the low $K \bar{K}$ mass region as a Coupled Channel Breit Wigner representing the δ , a good description of the D meson is obtained. In particular no $\eta(1275)$ is required by the data.
- b) The D meson is a $1^{++} (\delta \pi)$ state.
- c) The E/ι region is dominated by a $1^{++} K^* \bar{K}$ state which we identify with the E meson.

- d) There is some room in the data for a small 0^{-+} signal (mostly seen in the $K^* \bar{K}$ wave). If we interpret this signal as due to the ι , then its ratio of production with respect to the E/ι is about 14%.
- e) The presence of a π^0 in the final state reduces the amount of D and E/ι production.
- f) The $K^0, K^\pm \pi^\mp$ mass spectrum in the channel containing two extra charged pions shows no clear evidence of D or E/ι production.

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Figure captions

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

Fig. 2 Δ function distribution for the $K^0_1 K^\pm \pi^\mp$ channel.

Fig. 3 a) Effective mass $K^0_1 K^\pm \pi^\mp$ when one particle is identified as a K or ambiguous K/p.
b) Dalitz plot for events in the mass region 1.37 – 1.49 GeV of fig. 3a.

Fig. 4 Effective mass $K^0_1 K^\pm \pi^\mp$ for sample b) described in the text.

a) π^+ incident beam;

b) p incident;

c) sum.

Fig. 5 a) Effective mass $K^+ \pi^-$ and $K^- \pi^+$.

b) Effective mass $K^0_1 \pi^+$ and $K^0_1 \pi^-$.

c) Scatter plot $M(K^0_1 K^\pm \pi^\mp)$ vs $M(K^0_1 K^\pm)$.

d) Effective mass $K^0_1 K^\pm$. The dash-dot line shows the effect of removing the D region;
the dotted line shows the effect of removing the D and E/ι regions.

Fig. 6 Feynman x_F distributions for the slow proton, the central system and the fast particle.

Fig. 7 Fit of the D region:

a) Dalitz plot of the experimental data.

b) Dalitz plot of Monte-Carlo simulated data obtained by using the results of the fit
(the number of generated events is 50% more than the real data);

c) Superposition of the Monte-Carlo generated data on the $K \pi$ mass distribution;

d) Same as c) on the $K^0_1 K^\pm$ mass distribution.

Fig. 8 Dalitz plot for the E/ι region (experimental data):

a) π^+ incident;

b) p incident;

c) sum.

Fig. 9 Monte-Carlo Dalitz plot distributions of the relevant waves used in this analysis in the E/ι region.

Fig.10 Results of the Dalitz plot analysis:

a,b) π^+ incident;

c,d) p incident.

Fig.11 Results of the Dalitz plot analysis for the combined data:

a) 0^-+ contribution;

b) 1^{++} contribution;

c) full circle: raw mass distribution; open circle: phase space contribution resulting from the fit.

Fig.12 Data and Monte-Carlo simulation for the combined data using the results from the fit of the $K \bar{K} \pi$ mass region 1.36 – 1.40 GeV.

Fig.13 Same as 12 for the $K \bar{K} \pi$ mass region 1.40 – 1.44 GeV.

Fig.14 Same as 12 for the $K \bar{K} \pi$ mass region 1.44 – 1.48 GeV.

Fig.15 Geometrical acceptance as a function of the $K^0_1 K^\pm \pi^\mp$ effective mass. The full and dashed lines correspond to the selections a) and b) described in sect. 3.

Fig.16 a) Missing mass squared to all the measured tracks after having antiselected the "4C" events.

b) Effective mass $K^0_1 K^\pm \pi^\mp$ for the "1C" channel.

Fig.17 a) Δ function distribution for the $K^0_1 K^\pm \pi^\mp \pi^+ \pi^-$ channel:

b) $\pi^+ \pi^-$ effective mass (two entries per event);

c) $K^0_1 K^\pm \pi^\mp$ effective mass (two entries per event). The dashed histogram represents the sum of the $K^0_1 K^+ \pi^+$ and $K^0_1 K^- \pi^-$ mass spectra.

Fig. 1

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Fig. 10

Fig. 11

Fig. 12

Fig. 13

Fig. 14

Fig. 15

Fig. 16

$M^2(\pi^+ \pi^- \pi^+ \pi^-)$

$M(\pi^+ \pi^-)$ GeV

Fig. 17