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STUDY OF THE D(1285) AND E(1420) RESONANCES

PRODUCED IN $\bar{p}p$ ANNIHILATIONS AT 700-760 MeV/c

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ABSTRACT

In this paper we have investigated the properties of the D(1285) and E(1420) meson resonances using the five-body annihilation channels $\bar{p}p \rightarrow K\bar{K}\pi\pi\pi$ obtained in a large statistics experiment (28 events/ μbarn). The analysis favours the 1^+ spin-parity assignment for the D(1285) meson. The dominant decay mode of the D(1285) into $K\bar{K}\pi$ is found to be $\delta(970)\pi$. The situation concerning the E(1420) meson remains confused although not inconsistent with previous analyses. Partial cross sections on resonance production are also presented.

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1. INTRODUCTION

The D(1285) meson was discovered simultaneously in an analysis of the $\bar{K}\bar{K}\pi$ neutral system produced in $\bar{p}p$ annihilations at 1.2 GeV/c leading to multimeson final states of the type $\bar{K}\bar{K}\pi\pi$, $\bar{K}\bar{K}\pi\pi\pi$ and $\bar{K}\bar{K}\pi\pi\pi\pi$ [1, 2] and in the study of the reaction $\pi^- p \rightarrow \bar{K}\bar{K}\pi n$ over the momentum interval 1.7 to 4.2 GeV/c [3, 4]. In spite of the limited statistics and of the complexity of the multibody final states a determination of the resonance parameters was made and the isoscalar nature of the object was favoured. Branching ratios corresponding to different subreactions of the observed $\bar{K}\bar{K}\pi$ decay mode and possible spin parity assignments were also discussed, although no final conclusion was reached. A further analysis of the D-meson properties was pursued using data obtained in the same annihilation channels at 700 MeV/c [5] and in a larger data sample at 1.2 GeV/c [6]. Other decay modes were investigated using the multipion (5π , 7π) annihilation channels [7-9]. The decay sequence $D^0 \rightarrow \delta\pi \rightarrow \eta\pi\pi$ was established and better knowledge of the connection between the $\bar{K}\bar{K}$ threshold enhancement [10, 11] and the $\eta\pi$ decay mode of the $\delta(970)$ was also achieved. Besides the annihilation reactions, additional information on the properties of the D-meson was obtained in π^+d interactions [12], $\bar{K}^-p$ hypercharge exchange reactions [13] and $\pi^\pm p$ reactions [14-17]. Although a fair amount of data has been collected for the D-meson, a precise measurement of the branching ratios is not yet available and the spin parity assignment has not been unambiguously established. On the other hand, at a more specific level, no explanation seems to account for the lack of D-production in the $\bar{p}p$ annihilations at rest.

The E(1420) meson was detected in the study of the $(\bar{K}\bar{K}\pi)$ neutral system observed in the five-body channels $\bar{p}p \rightarrow \bar{K}\bar{K}\pi\pi\pi$ produced by the annihilation of antiprotons at rest [18]. From a detailed study of the production and decay properties of the E(1420) resonance the following set of quantum numbers $I^G_J = 0^+0^-$ was assigned. Further work on annihilation reactions at higher energies [5, 6] and on multipion final states [8, 9] has not provided significant additional evidence for the existence of this resonance. The complexity of the final states under

study, with large reflections from competing intermediate channels affecting relevant distributions for the analysis of the E(1420), makes difficult the study of the properties of this meson.

In this paper we present an analysis of the $K\bar{K}\pi$ system, with particular emphasis on the D(1285) and E(1420) meson resonances, produced in the final states

$$\bar{p}p \rightarrow K_S^0 K^{\pm} \pi^{\mp} \pi^+ \pi^- \quad (1)$$

$$K_S^0 K_S^0 \pi^+ \pi^- \pi^0 \quad (2)$$

$$K_S^0 K^{\pm} \pi^{\mp} Mm \quad (3)$$

$$K_S^0 \pi^+ \pi^- Mm \quad (4)$$

$$K_S^0 K^{\pm} \pi^{\mp} \pi^0 \quad (5)$$

$$K_S^0 \pi^+ \pi^- (K^0) \quad (6)$$

$$K_S^0 K_S^0 \pi^+ \pi^- \quad (7)$$

induced by antiprotons of 700 and 760 MeV/c. In the above list of reactions, the following notation is used: K_S^0 means a short lived K^0 seen to decay into $\pi^+ \pi^-$. Mm is for a missing mass larger than $(m_K + m_\pi)$ or larger than $2 m_\pi$ for reaction (4) and (3), respectively. (K^0) means an unseen K^0 requested by the fit.

In sect. 2 a brief description of the experimental data is given, and the values of the cross sections for the relevant final states are presented.

In sect. 3 we discuss the behaviour of the effective mass distributions for the different particle combinations, searching for intermediate resonant states. In particular, a detailed analysis of the $K\bar{K}\pi$ mass distributions with a determination of the mass and width of the D(1285) meson is presented. The C-parity, Isospin and G-parity quantum numbers are also discussed.

In sect. 4 we show the results of a maximum likelihood analysis of the five-body channels in terms of single and double resonance production. This study provides a determination of the relevant cross sections and allows a determination of the E(1430) parameters based on a more precise knowledge of the underlying background.

In sect. 5 we discuss the J^P assignment of the D-meson, the $(K\bar{K})_{I=1}$ interaction near threshold and the $K^*(890)K$ and $(K\bar{K})_{I=1}\pi$ decay modes.

Sect. 6 summarizes our conclusions.

2. EXPERIMENTAL DETAILS

The data for this analysis come from two exposures of the 80 cm Saclay Hydrogen Bubble Chamber to antiproton beams of 700 and 760 MeV/c momenta. The statistical sensitivities of these samples are 6 events/ μ barn at 700 MeV/c [5] and 22 events/ μ barn at 760 MeV/c, respectively. The scanning criteria selected all the events having at least a visible K^0 decay in the fiducial region. The measurements were processed through the standard CERN data handling programs. In table 1 we show the relevant details (number of events and cross sections) for the final states of interest for the present work.

3. EFFECTIVE MASS DISTRIBUTIONS

As can be seen in table 1 the cross sections for the six-body final states are negligible compared to those of the four- and five-body channels. Therefore, the multineutral final states (3) and (4) involve, mainly, two neutral particles ($\pi^0\pi^0$ and $K^0\pi^0$ respectively) and will be considered, for the analysis, as five-body channels.

It will be shown later that the D(1285) meson is clearly present in the five-body channels (1), (2) and (3) and is nearly absent in the four-body channels. Since the basic interest of this paper is the study of D and E mesons, in what follows we will restrict ourselves mainly to the study of the channels (1), (2), (3) and (4).

Qualitatively, the final state $\bar{p}p \rightarrow K_S^0 K^\pm \pi^\mp \pi^+ \pi^-$ (fig. 1) exhibits clear production of $K^*(890)$ and D(1285) resonances, and enhancements in the $K\bar{K}$ system near threshold and in the $K\bar{K}\pi$ system in the E(1420) region.

which, unfortunately, is located at the maximum of the phase space. For the channel $\bar{p}p \rightarrow K_S^0 K_S^0 \pi^+ \pi^- \pi^0$ (figs 2, 3) the $\omega(783)$ resonance appears to be the dominant contribution and there is some accumulation of events in the D(1285) region which becomes more prominent after removing the events with the $(3\pi)^0$ effective mass distribution in the ω region ($0.76 < M(\pi^+ \pi^- \pi^0) < 0.81$ GeV). The missing mass channels $\bar{p}p \rightarrow K_S^0 K_S^+ \pi^- \bar{M}m$ and $\bar{p}p \rightarrow K_S^0 \pi^+ \pi^- \bar{M}m$ (figs 4, 5) show some small contribution from D(1285) production in the relevant $K_S^0 K_S^+ \pi^-$ and $K_S^0 \pi^+ \pi^-$ effective mass distributions.

As a general comment, we note that the D-meson appears over a relatively smooth background with manageable signal to noise ratio, permitting the extraction of some of the resonance properties from a simplified analysis of the basic mass distributions. On the other hand, and as we have pointed out previously, the E(1420) meson is produced at the maximum of the $K\bar{K}\pi$ phase space, thus making it rather difficult to obtain the resonance parameters from the analysis of the $K\bar{K}\pi$ effective mass distributions. In this case, a better understanding of the background is clearly needed in order to get reliable results.

Finally, we have considered the possibility that the two isoscalar states belonging to the 1^{++} nonet would have similar masses and common decay channels by looking at the relevant mass distributions in finer bins. The observations do not support this suggestion.

3.1 Mass and width of the D-meson

As a general approach to extract the D-parameters we have fitted the $K\bar{K}\pi$ mass distributions for every channel where a significant contribution was observed, with an incoherent superposition of a s-wave Breit-Wigner form, with the resolution folded, and a low order polynomial in the mass describing the background. The fits were performed using a maximum likelihood method and, normally, a quadratic shape for the background was found to be a good approximation. The fitted region of the mass spectra was $1.15 < M(K\bar{K}\pi) < 1.40$ GeV.

For channel (2) the fit was made for the complete sample as well as for the subsample obtained by removing the large ω contribution ($0.76 < M(\pi^+\pi^-\pi^0) < 0.81$ GeV).

The results are displayed in figs 6, 7(a) and in table 2.

The values of M and Γ obtained in the various fits are consistent. Using the combined sample of final states (1), (2) (after removing the ω signal) and (3) we obtain the following determination of the resonance parameters

$$M_D = 1282.0 \pm 2.0 \text{ MeV}, \quad \Gamma_D = 28.3 \pm 6.7 \text{ MeV}.$$

In all the other channels a fit was not tried since the D(1285) meson signal was not significant.

For completeness we show in fig. 8 the $(K\bar{K}\pi)^0$ effective mass distributions for the four-body channel (5). An accumulation of events in the D-mass region can be seen and we cannot exclude a contribution from the E meson sitting over a very steep background.

3.2 C-parity - Isospin and G-parity of the D-meson

The $K_S^0 K_S^0 \pi^0$ decay mode for the D-meson observed in the final state (2), establishes the positive value of the C-parity. This result is confirmed by the small D-signal observed in the $(K_S^0 MM)$ mass distribution of channel (4) (fig. 5) compatible with the expected number of $K_S^0 K_S^0 \pi^0$ D-events with $K_S^0 \rightarrow \pi^0 \pi^0$.

The isospin assignment can be decided among the possible values 0 and 2, taking into account the ratio between the number of D-events observed in the $K_S^0 K_S^0 \pi^0$ and $K_S^0 K^\pm \pi^\mp$ decay channels. The expected values for this fraction, calculated from the Clebsch-Gordan coefficients and the K^0 decay ratios are 0.17 and 0.69 respectively. The experimental value 0.27 ± 0.08 obtained from the fits to the $K\bar{K}\pi$ mass distributions,

corrected for experimental K_S^0 losses, is consistent with the value $I = 0$, while the $I = 2$ can be ruled out at a 99.9% confidence level.

In the absence of data on the $K^+K^-\pi^0$ decay channel, we cannot perform a complete test on the $I = 1$ assignment. Nevertheless, using the observation that the $K_S^0K^+\pi^-$ decay mode is dominated by the two-body channel $D \rightarrow \delta(970)\pi$ (sect. 5) and that the $D \rightarrow K_S^0K_S^0\pi^0$ decay channel goes also preferentially through the $\delta(970)\pi^0$ mode (sect. 4.2), $I = 1$ is very unlikely. The $K\bar{K}\pi$ charged distributions shown in figs 7(b, c) are also consistent with the isoscalar assignment.

Additional information on the isospin of the D-meson can be obtained by comparing the intensities of the processes $\bar{p}p \rightarrow D^0\pi^0$ and $\bar{p}p \rightarrow D^{\pm}\pi^{\mp}$. The ratio $(\bar{p}p \rightarrow D^{\pm}\pi^{\mp})/\sigma(\bar{p}p \rightarrow D^0\pi^0)$ should be 0, larger than 1 and $3/2$ for the isospin values 0, 1 and 2 respectively. Taking into account appropriate Clebsch-Gordan coefficients and K^0 decays, we obtain that the ratios between the number of charged and neutral D-events detected in the final state $\bar{p}p \rightarrow K_S^0K^{\pm}\pi^{\mp}\pi^0$ has to be 0, > 1 and 9 for the three possible isospin values. Unfortunately, the quasi two-body $D\pi$ production is small (76 ± 26 $\bar{p}p \rightarrow D^0\pi^0$ events) and difficult to estimate due to the rapidly rising background (fig. 8). As a qualitative consistency check for the $I = 0$ assignment we have subtracted from the $K_S^0K^{\pm}\pi^{\mp}$ mass distribution, the $K_S^0K^{\pm}\pi^0$ histogram. The resulting distribution shows a small D-signal, in agreement with the expectations for an $I = 0$ value.

4. CHANNEL FIT ANALYSIS OF FIVE-BODY FINAL STATES

4.1 The final state $\bar{p}p \rightarrow K_S^0K^{\pm}\pi^{\mp}\pi^+\pi^-$

After the kinematic and ionization analysis a sample of 1021 four-constraint fit events were unambiguously assigned to this final state. The relevant distributions shown in fig. 1 seem to indicate that the $K^*(890)$ production represents an important contribution to the complete final state. In addition to that, structures in the $K\bar{K}$ and $K\bar{K}\pi$ systems are also apparent.

The possibility that these observations are entirely due to the production of $K^*(890)$ and phase space effects has been investigated using a matrix element [19] which includes symmetrization with respect to identical pions, and which allows interferences among the neutral and charged modes of the $K^*(890)$, with a degree of coherence which is optimized using a maximum likelihood method. Qualitatively, the results of this fit (fit 1 in table 3) are the following:

- (a) All the effective mass distributions are badly reproduced, except for the doubly charged $K^\pm \pi^\pm$, $K_S^0 K^\pm \pi^\pm$ and $\pi^\pm \pi^\pm$.
- (b) The $K\pi$ distributions, affected by $K^*(890)$ production, are still poorly described by the fit.
- (c) The threshold $K_S^0 K^\pm$ effect, the D(1285) and, to some extent, the E(1420) appear as clear structures, above the calculated $K^*(890)$ $K\pi\pi$ background, in the corresponding $K_S^0 K^\pm$ and $K_S^0 K^\pm \pi^\mp$ effective mass distributions (dashed curves in fig. 9).
- (d) The $\pi^+ \pi^-$ distribution shows an excess of events in the high mass region (fig. 9) which cannot be interpreted as due to $K^*(890)$ reflection.

In order to achieve a better overall description of the final state, amplitudes accounting for $\delta(970)$ and $\rho(760)$ production were introduced in the full transition probability. The $\rho(760)$ was parametrized as a p-wave Breit-Wigner form with resonance parameters ($M = 773$ MeV, $\Gamma = 152$ MeV) taken from the PDG tables [20]. The $K\bar{K}$ interactions near threshold ($\delta(970)$) was considered to be well represented by a scattering length amplitude, in the zero effective range approximation, with a real length of 2.5 fm. [11]. In preliminary fits it was found that the $\delta(970)$ was produced in associations with $\rho(760)$. The amplitude for double resonance production was taken as the product of single resonance amplitudes. The results of the fit (fit 2) are presented in table 3. This fit leads to a significant improvement in the description of the $K_S^0 K^\pm$ and $\pi^+ \pi^-$ effective mass distributions, although some discrepancies still persist. On the other hand the structures observed in the neutral $K\bar{K}\pi$ system cannot be described by the reflection of the competing processes introduced so far.

The previous remarks lead us to consider contributions of D(1285) and E(1420) production. The processes $D\pi^+\pi^-$, $D\rho(760)$ and $E\pi^+\pi^-$ were introduced in the fit. For the D-meson the values of the mass and width obtained in sect. 3 were used and for the E the values quoted in the PDG tables [20] were taken ($M = 1416$ MeV, $\Gamma = 60$ MeV). The decay matrix elements were written assuming the spin parity assignments $J^P(D) = 1^+$ and $J^P(E) = 0^-$ and the decay modes $\delta(970)\pi$ and $K^*(890)K$. However, the branching ratios were left as free parameters. The results of the fit (fit 3) are presented in table 3 and show a significant improvement in the value of the likelihood function, establishing the necessity for D and E production. The solid lines in fig. 9 are the projections of the overall fit on the $K_S^0 K^\pm$, $\pi^+\pi^-$ and $K_S^0 K^\pm \pi^\mp$ effective mass distributions. A discrepancy between the experimental $\pi^+\pi^-$ distribution and the projected solid curve is still observed. As can be seen in fig. 10 this deviation is mainly associated with the $\pi^+\pi^-$ system recoiling against the $K_S^0 K^\pm \pi^\mp$ system in the E(1420) meson region ($1.38 < M(K_S^0 K^\pm \pi^\mp) < 1.46$ GeV). The corresponding distribution for the D(1285) meson region ($1.253 < M(K_S^0 K^\pm \pi^\mp) < 1.313$ GeV) seems to be well described by fit 3 (dashed curves in fig. 10(a)).

In the past [18], this effect was explained assuming that the E(1420) meson was produced in the quasi two-body reaction

$$\bar{p}p \rightarrow E^0 \sigma ,$$

σ being a resonance state coupled to the $\pi^+\pi^-$ system and having a mass of ~ 445 MeV and a width of ~ 70 MeV. The lack of support for the existence of such an object forces us to look for a different explanation for the shape of this $\pi^+\pi^-$ distribution. In the new approach we consider the contribution of $K^*(890)K \rho(760)$ associated production, in the two different charge configurations $\bar{p}p \rightarrow K^+ K^*(890)^- \rho^0(760)$ and $\bar{p}p \rightarrow \bar{K}^0 K^{*0}(890) \rho^0(760)$, described by terms which account for Bose symmetrization and allow variable amount of coherence among the different amplitudes. This parametrization of the overall probability function seems to reproduce all the experimental distributions so far investigated. Using all the contributions listed in

table 3 for the fit 4, optimisation of the D and E parameters was achieved (sect. 5). The projections corresponding to the best solution are presented in fig. 1 (solid curves) and fig. 10 (solid curves). The following remarks are in order:

(a) The quasi-two body and three-body reactions $\bar{p}p \rightarrow D(1285) \rho(760)$, $KK^*(890) \rho(760)$ and $A_2(1300) \rho(760)\pi$ account for $\sim 50\%$ of the channel cross section.

(b) The contribution from reactions $\bar{p}p \rightarrow \delta(970) \rho(760)\pi$ and $K^*(890) \bar{K}^*(890)\pi$ is negligible.

(c) The contribution of the E(1420) meson is decreased when the $\bar{p}p \rightarrow KK^*(890) \rho(760)$ process is introduced in the description of the final state. Thus, the cross section for E-meson production is found to be $19.2 \pm 5.2 \mu\text{b}$ (table 3). Since the contribution from the $KK^*\rho$ amplitude is rather important, in spite of phase space limitations, some remarks are in order. Basically, what the data requires is a certain amplitude which enhances the high mass region of the $\pi\pi$ system recoiling against the $K^*(890)K$ system. Introducing the $\rho(760)$ amplitude improves the fit although that does not mean that we are necessarily dealing with an $I = 1, J^P = 1^-$ resonance. Nevertheless, we have performed two checks which suggest that in this amplitude the $\pi\pi$ system is in a $J = 1$ state:

(i) A simple parametrization of the $\pi\pi$ system as an s-wave Breit-Wigner with parameters $M = 860$, $\Gamma = 895$ MeV [21], gives a value of the likelihood function which is worse (by 54 units) than the one obtained in fit 4.

(ii) In the final state (3), the missing mass distribution recoiling against the $K\bar{K}\pi$ system with masses in the E(1420) region does not exhibit the pattern observed in fig. 10(b) as would be naively expected if this system had been dominated by an isoscalar contribution.

(d) Suggested by the important contribution of the reaction $\bar{p}p \rightarrow D(1285) \pi^+\pi^-$ in the five-body annihilation channels, a search was made to detect other final states in the same spin parity configuration $\bar{p}p \rightarrow 1^+0^-0^-$ (for the J^P assignment of the D(1285) see sect. 5). In particular we have looked for the process $\bar{p}p \rightarrow CK\pi$ [22, 23] with negative results.

(e) In addition to the comparison of many single effective mass distributions with the predictions calculated using the parameters obtained in the various fits listed in table 3, a detailed study of some scatter plots was made in order to confirm the necessity of including the contribution from double resonance production. Table 4 shows the results of a series of comparisons using a χ^2 test. The inclusion of an amplitude for the process $\bar{p}p \rightarrow KK^*(890) \rho(760)$ clearly improves the ratios χ^2/number of cells.

A further discussion of the properties of the D-meson is given in the next section.

4.2 The final state $\bar{p}p \rightarrow K_S^0 K_S^0 \pi^+ \pi^- \pi^0$

This channel is dominated by the production of the $\omega(783)$ resonance. In addition, small contributions from $K^*(890)$, $\delta(970)$ and $D(1285)$ mesons are detected in the relevant mass distributions (figs 2 and 3). A maximum likelihood analysis of the complete final state similar to the one described in sect. 4.1 was performed and the results corresponding to the best solution are presented in table 5. The projections of this solution on the experimental mass distributions are displayed as solid lines in figs 2 and 3. It may be noted that a reasonable description of the experimental mass distributions and scatter plots requires contribution of the intermediate channels $KK^*(890) \rho(760)$, $\delta(970) \rho(760)\pi$ and $A_2(1300) \rho(760)\pi$. The production cross sections for D- and E-mesons in this final state are found to be $6.7 \pm 2.4 \mu\text{b}$ and $5.6 \pm 3.2 \mu\text{b}$ respectively.

The $D(1285)$ amplitude was parametrized using the results obtained in sect. 4.1. Alternatively, we have considered the $D \rightarrow S^* \pi^0$ amplitude where the S^* was parametrized according to our previous investigation of the $K_S^0 K_S^0$ system [24]. The value obtained for the likelihood function with this parametrization is worse than the one corresponding to the fit shown in table 5 by 2.4 units.

5. THE SPIN AND PARITY OF THE D-MESON

The branching ratio of the D-meson into the decay channels $K^*(890)K$ and $\delta(970)\pi$, the form of the $\delta(970) \rightarrow K\bar{K}$ interaction and the spin parity assignment of the D were studied simultaneously using appropriate decay matrix elements [18, 19] and the competing processes listed in table 3 for the fit 4. For the spin parity analysis we restrict ourselves to the lower values of the abnormal series (0^- , 1^+ , 2^-). Only the final state (1) was considered for this analysis.

The results of the maximum likelihood analysis can be briefly summarized as follows:

(a) Using a scattering length amplitude for the $\delta(970)$ interaction with the standard real scattering length of 2.5 fm [20], we find that the dominant decay mode of the D into $K\bar{K}\pi$ is $\delta(970)\pi$. The inclusion of the $K^*(890)K$ mode does not improve at all the value of the likelihood. The branching ratio $D \rightarrow K^*K \rightarrow K_S^0 K^\pm \pi^\mp$ to $D \rightarrow \delta\pi \rightarrow K_S^0 K^\pm \pi^\mp$ is found to be 0.01 ± 0.10 .

(b) Considering, nevertheless, the two possible decay channels of the D, the $J^P = 1^+$ assignment seems to be preferred as shown below. In fig. 11 we show the behaviour of the likelihood function for the spin parity values 0^- , 1^+ , 2^- as a function of the scattering length. Denoting by $L_{\max}$ the best value of the likelihood function, which corresponds to $J^P = 1^+$, a scattering length of 2.5 fm and a branching ratio

$$\frac{D \rightarrow K(890)K \rightarrow K_S^0 K^\pm \pi^\mp}{D \rightarrow \delta(970)\pi \rightarrow K_S^0 K^\pm \pi^\mp} = 0.01,$$

and by L' , L'' the optimum values corresponding to the assignments 0^- and 2^- , we obtain the values $\Delta' = 2(L_{\max} - L') = 4.2$ and $\Delta'' = 2(L_{\max} - L'') = 11$, which in the spirit of the Δ test [25] favours the 0^- and 1^+ value. When the likelihood values, for the three J^P assignments, are compared at the standard value of the scattering length [10, 11] we obtain the differences $\Delta' = 6.0$ and $\Delta'' = 11.0$ consequently, it is possible to exclude the 0^- and 2^- values with 96% and 99% confidence levels, respectively.

(c) The $\bar{K}K\pi$ decay Dalitz plot for events in the D-region ($1.253 < M(K_S^0 K^\pm \pi^\mp) < 1.313$ GeV) and the corresponding effective mass distributions were compared, using a simple χ^2 test, with the projections calculated from the best solutions for the three J^P assignments considered in the fits. The results are presented in fig. 12 and table 6 and show poor discrimination among the various hypothesis. Basically, this negative result is due to the limited statistics and the substantial amount of background.

6. CONCLUSIONS

From a high statistics (28 events/ μb) experiment we have detected a good D-meson signal in the $(\bar{K}K\pi)^0$ combinations in the five-body channel $\bar{p}p \rightarrow \bar{K}K 3\pi$. Using the maximum likelihood channel fit analysis involving only single and double resonance production, good fits to the observed mass distributions have been obtained. The best values of the parameters obtained for the D-meson are

$$\text{Mass} = 1282.0 \pm 2.0 \text{ MeV}; \quad \text{Width} = 28.3 \pm 6.7 \text{ MeV};$$

$$\text{Spin parity } (J^P) = 1^+ \text{ strongly favoured, isospin } (I^G) = 0^+.$$

The dominant decay mode of the D-meson giving rise to $\bar{K}K\pi$ in the above reaction is found to be through $\delta(970)\pi$. The cross section for D-production in the final state $K_S^0 K^\pm \pi^\mp \pi^+ \pi^-$ is found to be $16.5 \pm 2.9 \mu\text{b}$. We have also determined the following cross sections for quasi two-body processes involving D-production:

$$\sigma(\bar{p}p \rightarrow D^0 \pi^0 \rightarrow (K_S^0 K^\pm \pi^\mp) \pi^0) = 5.1 \pm 1.0 \mu\text{b},$$

$$\sigma(\bar{p}p \rightarrow D^0 \eta \rightarrow (K_S^0 K^\pm \pi^\mp) \eta) = 4.1 \pm 1.0 \mu\text{b},$$

$$\sigma(\bar{p}p \rightarrow D^0 \rho^0 \rightarrow (K_S^0 K^\pm \pi^\mp) \pi^+ \pi^-) = 5.2 \pm 2.1 \mu\text{b}.$$

Though we see an enhancement corresponding to the E(1420) meson in the same $\bar{K}K\pi$ mass spectra in the five-body final state mentioned above,

the background under it makes it difficult to extract the parameters of this resonance unlike the case of the D-meson. A strong competitor for the enhancement at the E-meson mass is found to be from the channel $K^*(890)\bar{K}p$ in spite of it being limited by phase space. The parameters deduced from our analysis for the E-meson are

$$\text{Mass} = 1417.5 \pm 4 \text{ MeV and width} = 53 \pm 20 \text{ MeV,}$$

which are consistent with the results previously obtained [18]. From our analysis we have deduced a cross section of $19.2 \pm 5.2 \text{ } \mu\text{b}$ for E-production in the final state $K_S^0 K^+ \pi^- \pi^+ \pi^-$, after due allowance is made for the strongly competing channel $K^* \bar{K}p$, whose contribution to the same final state is deduced to be $38.8 \pm 5.4 \text{ } \mu\text{b}$. Because of the existence of a relatively large background under the E-signal in the reaction we have studied, we believe that a study of the E-meson requires a more convenient production reaction. The E-production in the four-body final state $K_S^0 K^+ \pi^- \pi^+ \pi^-$ is found to be quite small and therefore not suitable for detailed analysis.

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TABLE CAPTIONS

- Table 1 Number of events and cross sections. The cross sections have been corrected to take into account the unseen decays of the K_S^0 .
- Table 2 Results of the mass fits.
- Table 3 Results of the fits to the channel $\bar{p}p \rightarrow K_S^0 K^\pm \pi^\mp \pi^+ \pi^-$.
- Table 4 Results of the χ^2 tests on two-dimensional distributions for the channel $\bar{p}p \rightarrow K_S^0 K^\pm \pi^\mp \pi^+ \pi^-$.
- Table 5 Results of the best fit to the channel $\bar{p}p \rightarrow K_S^0 K_S^0 \pi^+ \pi^- \pi^0$.
- Table 6 χ^2 tests for the decay Dalitz plot of the D-meson.

Table 1

Final state	700 MeV/c		750 MeV/c	
	Number of events	$\sigma(\mu\text{b})$	Number of events	$\sigma(\mu\text{b})$
1 $K_S^0 K^{\pm} \pi^{\mp} \pi^+ \pi^-$	206	100 ± 12	815	100.8 ± 6.2
2 $K_S^0 K_S^0 \pi^+ \pi^- \pi^0$	326	173 ± 17	878	139.1 ± 8.3
3 $K_S^0 K^{\pm} \pi^{\mp} M\pi$	174	55 ± 22	647	60.4 ± 3.0
4 $K_S^0 \pi^+ \pi^- M\pi$	454	126 ± 15	1786	156.3 ± 7.0
5 $K_S^0 K^{\pm} \pi^{\mp} \pi^0$	2085	720 ± 38	6891	612.9 ± 14.6
6 $K_S^0 \pi^+ \pi^- (K^0)$	1305	568 ± 25	4697	442.4 ± 11.8
7 $K_S^0 K_S^0 \pi^+ \pi^-$	484	237 ± 20	1464	215.8 ± 11.4
8 $K_S^0 K^{\pm} \pi^{\mp} \pi^+ \pi^- \pi^0$	14	10 ± 3	57	7.2 ± 1.1
9 $K_S^0 K_S^0 \pi^+ \pi^+ \pi^- \pi^-$	0	-	0	-
10 $K_S^0 \pi^+ \pi^+ \pi^- \pi^- (K^0)$	2	-	8	-
11 $K_S^0 K_S^0 \pi^+ \pi^- M\pi$	3	1.7 ± 1.1	25	3.9 ± 0.8

Table 2

Channel	Selection	Average Resolution MeV	M MeV	Γ MeV	Number of D-events
$\bar{p}p \rightarrow K_S^0 K_S^{\pm} \pi^{\mp} \pi^+ \pi^-$		4	1281.5 ± 2.4	34.0 ± 9.3	212 ± 22
$\rightarrow K_S^0 K_S^0 \pi^+ \pi^- \pi^0$		5	1279.0 ± 8.3	34.8 ± 22.0	58 ± 15
$\rightarrow K_S^0 K_S^{\pm} \pi^{\mp} \pi\pi$		8	1283.6 ± 4.0	$14.0 \begin{smallmatrix} + 16.0 \\ - 14.0 \end{smallmatrix}$	47 ± 15
$\rightarrow K_S^0 K_S^0 \pi^+ \pi^- \pi^0$	ω out	5	1281.6 ± 4.2	28.0 ± 12.0	52 ± 17

Table 3

Processes	Percentages				Cross Sections (nb)
	Fit 1	Fit 2	Fit 3	Fit 4	
$\bar{p}p \rightarrow K_S^0 K^\pm \pi^\mp \pi^\pm \pi^\mp$ phase space	47.7 ± 4.1	15.7 ± 4.1	~ 0	5.5 ± 4.0	5.5 ± 4.4
$\bar{p}p \rightarrow K_S^0 K^\pm \pi^\mp \rho^0$		12.1 ± 5.7	~ 0	8.0 ± 3.4	8.1 ± 3.5
$\bar{p}p \rightarrow \phi^\pm \rho^0 \pi^\mp$		24.6 ± 4.3	9.2 ± 2.9	0	-
$\bar{p}p \rightarrow D^0 \pi^+ \pi^-$			15.8 ± 8.5	11.2 ± 2.1	11.3 ± 2.2
$\bar{p}p \rightarrow D^0 \rho^0$			13.0 ± 6.8	5.2 ± 2.1	5.2 ± 2.1
$\bar{p}p \rightarrow E^0 \pi^+ \pi^-$			30.6 ± 5.0	19.0 ± 5.0	19.2 ± 5.2
$\bar{p}p \rightarrow A_2^\pm \rho^0 \pi^\mp$			5.0 ± 1.1	4.6 ± 1.1	4.6 ± 1.1
$\bar{p}p \rightarrow K^{*\pm} K^{*0} \pi^\mp$			~ 0	~ 0	-
$\bar{p}p \rightarrow K^* \rho K$				38.5 ± 4.8	38.8 ± 5.4
$\bar{p}p \rightarrow K^* K \pi \pi$	52.3 ± 4.2	47.6 ± 3.6	25.4 ± 4.1	8.0 ± 4.8	8.1 ± 4.9
Log likelihood	6982.0	7110.7	7202.1	7239.2	

Table 4

Distributions	χ^2 /Number of cells		
	$M^2(K_S^0 \pi^\pm)$ vs $M^2(K^\pm \pi^\mp)$	$M^2(K_S^0 \pi^\pm)$ vs $M^2(\pi^+ \pi^-)$	$M^2(K^\pm \pi^\mp)$ vs $M^2(\pi^+ \pi^-)$
Fit 1	120/68	280/63	276/65
Fit 2	121/68	133/63	131/65
Fit 3	73/68	133/63	131/65
Fit 4	72/68	53/63	63/65

Table 5

Process	Percentages	Cross section (μbarn)
$\bar{p}p \rightarrow K_S^0 K_S^0 \omega$	59.2 ± 2.5	82.3 ± 3.5
$\bar{p}p \rightarrow \delta \rho \pi$	11.6 ± 2.0	16.2 ± 2.7
$\bar{p}p \rightarrow D^0 \pi^+ \pi^-$	3.0 ± 1.4	4.2 ± 1.9
$\bar{p}p \rightarrow D^0 \rho^0$	1.8 ± 1.1	2.5 ± 1.5
$\bar{p}p \rightarrow E^0 \pi^+ \pi^-$	4.0 ± 2.4	5.6 ± 3.2
$\bar{p}p \rightarrow A_2^0 \rho \pi$	2.6 ± 0.7	3.6 ± 1.0
$\bar{p}p \rightarrow K^* \rho K$	11.8 ± 3.0	16.5 ± 4.1
$\bar{p}p \rightarrow K^* K \pi \pi$	6.0 ± 2.4	8.3 ± 3.3

Table 6

J^P	$M(K_S^0 K^{\pm})$	$M(K_S^0 \pi^{\pm})$	$M(K^{\pm} \pi^{\mp})$	Number of events (*)
0^-	30.0/14	18.0/15	14.7/15	327
1^+	24.9/14	15.3/15	14.2/15	319
2^-	26.2/14	17.2/15	14.1/15	304

(*) Predicted number of combinations in the mass region $1.253 < M(K\bar{K}\pi)^0 < 1.313$ GeV. The experimental number of combinations is 331.

FIGURE CAPTIONS

- Fig. 1 (a-e) $(K_S^0 K^\pm) - (K_S^0 \pi^\pm) - (\pi^+ \pi^-) - (K^\pm \pi^\mp) - (K_S^0 K^\pm \pi^\mp)$ effective mass distributions for the final states $\bar{p}p \rightarrow K_S^0 K^\pm \pi^\mp \pi^+ \pi^-$. The dashed lines are the phase space calculations and the solid lines are the projections of the best fit to the complete final state described in sect. 4.1.
- Fig. 2 (a-e) $(K_S^0 K_S^0) - (K_S^0 \pi^0) - (K_S^0 \pi^\pm) - (\pi^\pm \pi^0) - (\pi^+ \pi^-)$ effective mass distributions for the final state $\bar{p}p \rightarrow K_S^0 K_S^0 \pi^+ \pi^- \pi^0$. The dotted lines are the phase space calculations and the solid lines are the projections of the best fit to the complete final state described in section 4.2.
- Fig. 3 (a,b) $(\pi^+ \pi^- \pi^0) - (K_S^0 K_S^0 \pi^0)$ effective mass distributions for the final state $\bar{p}p \rightarrow K_S^0 K_S^0 \pi^+ \pi^- \pi^0$. The dashed histogram was obtained after removing events with $0.76 < M(3\pi) < 0.81$ GeV. The dotted lines are the phase space calculations and the solid lines are the projections of the best fit to the complete final state described in sect. 4.2.
- Fig. 4 (a-e) $(K_S^0 K^\pm) - (M\pi) - (K_S^0 \pi^\pm) - (K^\pm \pi^\mp) - (K_S^0 K^\pm \pi^\mp)$ effective mass distributions for the final states $\bar{p}p \rightarrow K_S^0 K^\pm \pi^\mp M\pi$.
- Fig. 5 (a-d) $(M\pi) - (K_S^0 \pi^\pm) - (\pi^+ \pi^-) - (K_S^0 M\pi)$ effective mass distributions for the final state $\bar{p}p \rightarrow K_S^0 \pi^+ \pi^- M\pi$.
- Fig. 6 (a-c) $(K_S^0 K^\pm \pi^\mp) - (K_S^0 K_S^0 \pi^0) - (K_S^0 K^\pm \pi^\mp)$ effective mass distributions for the final states $\bar{p}p \rightarrow K_S^0 K^\pm \pi^\mp \pi^+ \pi^-$, $K_S^0 K^\pm \pi^\mp \pi^+ \pi^-$, $K_S^0 K^\pm \pi^\mp M\pi$.
- (d) $(K_S^0 K_S^0 \pi^0)$ effective mass distribution for the final state $\bar{p}p \rightarrow K_S^0 K_S^0 \pi^+ \pi^- \pi^0$ after removing the events with the $\pi^+ \pi^- \pi^0$ effective mass distribution in the ω region ($0.76 < M(3\pi) < 0.81$ GeV). The curves are the results of the mass fits described in the sect. 3 of the text.

FIGURE CAPTIONS (Cont'd)

- Fig. 7 (a) $(\bar{K}K\pi)^0$ effective mass distribution for the combined sample of five-body final states $\bar{p}p \rightarrow K_S^0 K^\pm \pi^\mp \pi^+ \pi^-$, $K_S^0 K_S^0 \pi^+ \pi^- \pi^0$, $K_S^0 K^\pm \pi^\mp \pi^0$. The curve is the result of the mass fit described in sect. 2.
- (b) $(\bar{K}K\pi)^\pm$ effective mass distribution for the final state $\bar{p}p \rightarrow K_S^0 K_S^0 \pi^\pm \pi^\mp \pi^0$.
- (c) $(\bar{K}K\pi)^{\pm\pm}$ effective mass distribution for the final state $\bar{p}p \rightarrow K_S^0 K^\pm \pi^\mp \pi^+ \pi^-$.
- Fig. 8 $K_S^0 K^\pm \pi^\mp$ effective mass distribution for the final states $\bar{p}p \rightarrow K_S^0 K^\pm \pi^\mp \pi^0$.
- Fig. 9 (a-c) $(K_S^0 K^\pm) - (\pi^+ \pi^-) - (K_S^0 K^\pm \pi^\mp)$ effective mass distributions for the final states $\bar{p}p \rightarrow K_S^0 K^\pm \pi^\mp \pi^+ \pi^-$. The dotted lines are the projections of fit 1 (with only $K^* K\pi\pi$ amplitudes). The solid lines are the projections of fit 3 (with $K^* K\pi\pi$, $KK\rho\pi$, $\delta\rho\pi$, $E\pi\pi$ and $D\pi\pi$ amplitudes).
- Fig. 10 (a) $(\pi^+ \pi^-)$ effective mass distribution recoiling against the $(K_S^0 K^\pm \pi^\mp)$ combinations in the D-region ($1.253 < M(K_S^0 K^\pm \pi^\mp) < 1.313$ GeV) for the final state $\bar{p}p \rightarrow K_S^0 K^\pm \pi^\mp \pi^+ \pi^-$. The dotted line is the projection of fit 3 (with $K^* K\pi\pi$, $KK\rho\pi$, $\delta\rho\pi$, $E\pi\pi$ and $D\pi\pi$ amplitudes). The solid line is the projection of fit 4 (which includes also the $K^* \rho K$ amplitude).
- (b) (Same as (a) but for the E-region ($1.38 < M(K_S^0 K^\pm \pi^\mp) < 1.46$ GeV)).
- Fig. 11 Value of the maximum likelihood function versus the $\bar{K}K$ scattering length near threshold for the various spin-parity assignments of the D-meson.
- Fig. 12 (a-c) $(K_S^0 K^\pm) - (K_S^0 \pi^\pm) - (K^\pm \pi^\mp)$ effective mass projections of the D-meson Dalitz plot ($1.253 < M(K_S^0 K^\pm \pi^\mp) < 1.313$ GeV). The solid lines are the projections of the overall fit assuming the J^P assignment 1^+ .

FIG.1

FIG. 2

FIG. 3

FIG. 4

FIG. 5

FIG. 6

FIG. 6

FIG. 7

FIG. 7

FIG. 8

FIG. 9

FIG. 10

SCATTERING LENGTH (fm)

FIG. 1)

Fig.12