PROPERTIES OF THE $\bar{p}p$ ANNIHILATIONS INTO STRANGE PARTICLES AT 702 AND 757 MEV/c

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ABSTRACT

$\bar{p}p$ annihilations, leading to the production of at least one neutral K-meson in the final state, have been studied in the incident momentum region of 700-760 MeV/c. Topological cross sections and cross sections for the various exclusive final states are presented. Detailed analyses of the different final states have been carried out to study the importance of resonance production and of quasi-two-body and quasi-three-body processes.

1. INTRODUCTION

Experimental data on proton antiproton annihilations are still limited after several years of research in this field. The most complete review goes back to 1969 [1]. It is difficult, in these conditions, to test the theoretical ideas which have been proposed to interpret those complex reactions. At low energy, $\bar{p}p$ annihilations have been found to be a rich source of information on meson resonances, both in production and in formation experiments. This information depends very much on the incident momentum of the interacting antiprotons. In annihilations at rest, for instance, the $E(1420)$ and $Q(1250)$ mesons are copiously produced, but not the $D(1285)$, whereas the reverse is true for annihilations in flight.

In an attempt to improve our knowledge in this field, we have accumulated data on $\bar{p}p$ annihilations with strange particle production up to a sensitivity of ~ 30 events per μb , at incident momenta around 730 MeV/c. In the following, we present our results on cross sections, 2, 3, 4, 5 and 6-body annihilations, explain why the $F_1(1540)$ previously reported in a similar experiment is not a resonance and compare various quasi two-body annihilations.

2. EXPERIMENTAL DETAILS

The data used in this analysis come from two sets of exposures of the 80 cm Saclay hydrogen bubble chamber to a separated beam of antiprotons from the CERN PS.

In the two sets of exposures, 0.37×10^6 and 1.6×10^6 pictures have been taken with an average incident momentum at the annihilation vertex of 702 and 757 MeV/c respectively. Fig. 1 shows the incident momentum distribution for all the events and table 1 summarizes the main features of the experimental conditions.

To obtain a convenient flux of antiprotons in the target, the beam was tuned to 800 MeV/c and the separated antiprotons were degraded by a lead absorber placed in front of the bubble chamber. The average number of antiprotons per picture was 10.3. The π^- and μ^- beam contamination was easily determined by ionization in the bubble chamber. Altogether it represents 14% of the beam particles.

The statistical sensitivity of the combined sample is 28 events/ μb . The scanning criteria selected all the events having at least a visible K^0 decay in the fiducial region. The entire film was scanned twice and the overall scanning efficiency was closed to one.

The measurements were processed through the standard CERN data handling programs (Thresh-Grind-Slice). The overall efficiency of this process was topology dependent and varies from 0.97 for the simplest topologies to 0.72 for the more complex ones, being 87% in average.

The events were then distributed among the various possible kinematical hypotheses. The identification was completed by a visual estimate of the ionization. The kinematic fit corresponding to the selected hypothesis was declared correct when its probability was larger than 0.004. The events satisfying these conditions for several hypotheses were declared "ambiguous" and were not used in the channel analyses except for checks. The above conditions were applied to the second exposure (757 MeV/c). For the first exposure (702 MeV/c), the events were simply assigned to the hypothesis giving the best kinematic probability, unless this decision was not compatible with a visual estimation of the ionization. We shall see in the following that the more rigorous approach followed for the second exposure led to new conclusions concerning the observation of the $F_1(1540)$ resonance.

Some events are lost when the K^0 decay apex occurs either within 2 mm to the production vertex or outside the visible fiducial volume of the chamber. These losses were corrected by means of a weight attached to each event. Since no significant difference was observed between the weighted and unweighted distributions the weights were only used for the cross section calculations.

For the analysis of the two-body reactions $\bar{p}p \rightarrow K_S^0 K_S^0$ and $\bar{p}p \rightarrow K_S^0 K_L^0$ we have included data from two other experiments:

- (a) A formation experiment performed by a College de France-Pisa collaboration. It consists of 10 exposures of the 80 cm Saclay hydrogen bubble chamber to separated antiproton beams with a momentum at the annihilation vertex which varies between 370 MeV/c and 1127 MeV/c. A more complete description of the experimental details can be found in ref. [2].

(b) The production experiment described in ref. [3]. It is also an exposure of the 80 cm Saclay HBC to a separated $\bar{p}$ beam with a momentum distribution at the interaction vertex centred at 1170 MeV/c.

The beam momenta and statistics of these two experiments are given in table 2.

3. CROSS SECTIONS

To estimate the $\bar{p}p$ total cross section, the total length of interacting and non-interacting incident antiproton tracks which cross a given fiducial volume has been measured. Correcting for undetected $\bar{p}p$ elastic scattering at small angle (~ 2 mb), we get the following values

$$\begin{array}{ll} 702 \text{ MeV/c} & \sigma_t = 140 \pm 3 \text{ mb} \\ 757 \text{ MeV/c} & \sigma_t = 135 \pm 2 \text{ mb.} \end{array}$$

The errors do not include systematic errors which are estimated to represent ≈ 2 mb. These results are in good agreement with the recent accurate total cross section measurements of Hamilton et al. [4], who find $\sigma_t = 138$ mb at 702 MeV/c and 133 mb at 757 MeV/c.

To obtain the total $\bar{p}p$ annihilation cross sections, we interpolate the measurements of Coupland et al. [5] and of Alston-Garnjost et al. [6] for the $\bar{p}p$ elastic scattering and charge exchange cross sections, respectively, and after subtraction, we get 77 ± 4 and 74 ± 5 mb for the total $\bar{p}p$ annihilation cross sections at 702 and 757 MeV/c incident momentum, respectively.

The topological cross sections for annihilations with one or two $K_S^0 \rightarrow \pi^+\pi^-$ decays are given in table 3. They are corrected for scanning inefficiencies and losses due to undetected $K_S^0 \rightarrow \pi^+\pi^-$ decays. The channel cross sections, given in table 4, are corrected for measurement inefficiencies and for non-observable K_S^0 decays, taking a branching ratio $B = K_S^0 \rightarrow \pi^+\pi^- / K_S^0 \rightarrow \text{all} = 0.686$. The channel cross sections including a K_L^0 are obtained from the following relation,

$$\sigma(K_S K_L + \text{anything}) = \sigma_1 - 2(1 - BP)\sigma_2$$

where σ^1 is the cross section for $\bar{p}p \rightarrow K_s^0(K^0) + \text{anything}$ and σ^2 for $\bar{p}p \rightarrow K_s^0 K_s^0 + \text{anything}$, (K^0) representing an unobservable K^0 ; P is the average detection probability of K_s^0 within the fiducial volume.

4. TWO-BODY ANNIHILATIONS

Recently, two-body annihilations $\bar{p}p \rightarrow \pi\pi$ and $\bar{p}p \rightarrow K\bar{K}$ have been extensively studied at low energy to investigate the formation of $\bar{p}p$ resonances in the s-channel. However, the data available below 800 MeV/c are still too limited to allow a detailed partial wave analysis.

As indicated in sect. 2, the statistics used in this analysis include data at various beam momenta which have been grouped around eight average values, i.e.: 370, 430, 460, 570, 702, 757, 980 and 1170 MeV/c. The samples at 702, 757 and 1170 are based on high statistics and are therefore used as reference points in our analysis.

Fig. 2 gives the measured cross sections for the reaction

$$\bar{p}p \rightarrow K_s^0 K_s^0 \quad (1)$$

and

$$\bar{p}p \rightarrow K_s^0 K_L^0 \quad (2)$$

at the eight average momenta of this experiment. The reaction (1) cross sections are negligible at small energies and increase slowly with the incident momentum, whereas reaction (2) cross sections show the opposite behaviour. For annihilations at rest, the suppression of reaction (1) is explained by the dominance of the $C = -1$ 3S_1 initial state, but this "explanation" cannot be easily extended to annihilations in flight. It may well be that dynamical effects, like the formation of $C = -1$ resonances in the s-channel, enhance the cross sections for reaction (2). However, the reaction (2) cross section behaviour does not show significant local enhancements possibly due to the presence of narrow $C = -1$ resonances and does not support, in particular, the claims by Benvenuti et al. [7] for the existence of a narrow $J^P = 1^-$ resonance in the vicinity of 1950 MeV.

The folded angular distributions for reaction (2) are shown in fig. 3. The continuous lines correspond to the result of a fit using a Legendre polynomial expansion. The fits were performed applying a maximum likelihood method except for the momenta where the $\bar{p}p \rightarrow K_S^0 K_S^0$ channel is not negligible. At these momenta a chi-squared fit to the angular distribution was obtained after subtracting the $K_S^0 K_S^0$ from the $K_S^0(K^0)$ final states.

Table 5 gives the values of the coefficients of the Legendre polynomial together with a χ^2/ND estimate. Fig. 4 shows the behaviour of a_2/a_0 , a_4/a_0 and a_6/a_0 as a function of the total energy. The fact that the ratio a_2/a_0 is different from zero excludes a pure 3S_1 initial state and suggests the presence of large D waves (3D_1 , 3D_3 or both). Its value decreases with energy and there is no indication of a maximum at 1950 MeV. The ratio a_4/a_0 is large and negative, suggesting the presence of 3D_3 or 3G_3 waves and interferences between these waves with lower ones. This result disagrees with ref. [7] which assumes that a_4/a_0 is zero in the complete energy region. The most striking result of this polynomial decomposition is the importance of a_6/a_0 which is negative and certainly different from zero at the four intermediate energies, showing a minimum at 1950 MeV. Its interpretation requires the existence of a substantial contribution of the 3G_3 wave.

5. THREE-BODY ANNIHILATIONS $\bar{p}p \rightarrow KK\pi$

We observe the following three-body annihilation reactions:

$$\bar{p}p \rightarrow K_S^0 K^\pm \pi^\mp \quad (3)$$

$$\bar{p}p \rightarrow K_S^0 K_S^0 \pi^0 \quad (4)$$

The cross sections measured for these reactions are given in table 4.

The three-body annihilations represent an important fraction of the annihilations with strange particles. The $K_S^0 K^\pm \pi^\mp$ rate goes through a maximum around 700 MeV/c, whereas the $K_S^0 K_S^0 \pi^0$ rate remains approximatively constant between 0 and 1.2 GeV/c [8].

Fig. 5 shows the Dalitz plots for reaction (3) at 702 MeV/c and 757 MeV/c. Fig. 6 shows the $K_S^0 \pi^\pm$, $K^\pm \pi^\mp$, $K_S^0 K^\pm$ effective mass spectra of the combined samples. One observes a large production of $K^*(892)$, particularly for the charged mode, a clear $A_2(1310)$ production, and some indication for the $K^*(1420)$ production in the neutral mode. In contrast to $\bar{p}p$ annihilations at rest [9], there is no evidence for an accumulation at the $K_S^0 K^\pm$ threshold.

The masses and widths of the $K^*(892)$ and $A_2(1310)$ mesons have been determined by fitting to the $K\pi$ and $K\bar{K}$ mass spectra Breit-Wigner distributions [10] and found to be equal to

$$\begin{aligned} K^*(892)^\pm & \quad M = 890.7 \pm 0.9 \text{ MeV} \quad \Gamma = 45.8 \pm 3.6 \text{ MeV} \\ K^*(892)^0 & \quad M = 898.4 \pm 1.4 \text{ MeV} \quad \Gamma = 45.9 \pm 4.8 \text{ MeV} \\ A_2(1310)^\pm & \quad M = 1324 \pm 5 \text{ MeV} \quad \Gamma = 128 \pm 5 \text{ MeV}. \end{aligned}$$

The implications of these results for the $K^*(892)$ electromagnetic mass difference $\Delta M = 7.7 \pm 1.7 \text{ MeV}$ have been discussed in [10].

To obtain a quantitative interpretation of the Dalitz plots, we have performed a series of fits which assume an incoherent superposition of terms representing the production of $K^*(892)$, $A_2(1310)$, $K^*(1420)$ and terms corresponding to $K\pi$ s-waves of the form

$$T^2 = \left| \frac{1}{1 - iaq} \right|^2, \quad ,$$

where q is the relative $K\pi$ momentum and a is the $I = 1/2$ scattering length. We have not considered the $I = 3/2$ scattering length. The resonance terms are built as the products of Breit-Wigner distributions and decay angular distributions of the form

$$\begin{aligned} (J = 1): \quad I(\cos\theta) &= \frac{3}{4} [(1 - \rho_{00}) + (3 \rho_{00} - 1) \cos^2\theta] \\ (J = 2): \quad I(\cos\theta) &= \frac{15}{8} [3\rho_{00}(\cos^2\theta - 1/3) + 4\rho_{11}(1 - \cos^2\theta)\cos^2\theta + \\ &\quad + \rho_{22}(1 - \cos^2\theta)^2], \end{aligned}$$

the masses and widths of the $K^*(892)$ and $A_2(1310)$ being fixed to the values given above. For the $K^*(1420)$, we used $M = 1434 \text{ MeV}$ and $\Gamma = 100 \text{ MeV}$.

The results of the fits are given in table 6. The cross sections are corrected for the branching ratios of the resonances; in particular cross sections for the $A_2(1310)$ resonance have been arrived at on the basis of its observed $K\bar{K}$ decay mode.

Dividing our data into various production angles for the $(K\pi)^\pm$, $(K\pi)^0$ and $(KK)^\pm$ systems, and repeating the analysis of the Dalitz plots for each of these samples, we have determined the production angular distributions for the $K^{*\pm}(892)$, $K^{*0}(892)$ and $A_2^\pm(1310)$ as shown in fig. 7. One sees that the $K^{*0}(892)$ production is compatible with isotropy. This is not the case of the $K^{*\pm}(892)$ which shows a strong anisotropic and asymmetric distribution, also reproduced, to some extent, by the $A_2^\pm(1310)$ distribution, suggesting the presence of t-channel exchanges even at these low incident momenta, rather than s-channel effects which would lead to a more similar behaviour of the $K^{*\pm}(892)$ and $K^{*0}(892)$ distributions. Table 7 gives the results of truncated Legendre polynomial expansion fits to the distributions at 757 MeV/c. The values at 702 MeV/c (not shown in the table) are not significantly different from 757 MeV/c.

Fig. 8 shows the Dalitz plot for reaction (4), the 702 MeV/c and 757 MeV/c data being combined. Fig. 9 shows the $K_s^0\pi^0$ and $K_s^0K_s^0$ mass spectra. In contrast to reaction (3), the $K^*(892)$ is barely visible, whereas the $K_s^0K_s^0$ mass spectrum exhibits several enhancements which may be attributed to the $S^*(980)$, the $(f^0 + A_2)$ complex and the $f'(1515)$. A quantitative analysis of this Dalitz plot, following the method described for reaction (3) gives the following results:

Channel	Fraction	Cross section (μb)
$S^*(980)\pi^0$	0.21 ± 0.02	46 ± 9
$K^*(892)K_s^0$	0.10 ± 0.02	17 ± 4
$f'(1515)\pi^0$	0.11 ± 0.02	24 ± 5
$(f + A_2)^0\pi^0$	0.06 ± 0.02	372 ± 140
Phase space	0.52 ± 0.03	30 ± 10

For the $S^*(980)$, we have used the following values for the mass and width: $M = 1040$, $\Gamma = 65$ MeV. The interference introduced in the fit between the $(f + A_2)$ and f' amplitudes does not allow to interpret the peak observed at the f' mass with its normal quoted width of 67 MeV. Instead, the data need a mass and a width of 1513 ± 3 MeV and 26 ± 8 MeV, respectively. Although we have no explanation for this abnormal width, the large fraction of phase-space required by the fit suggests that the formalism applied to interpret reaction (4) may not be the adequate one. The statistics are too limited to allow a more detailed analysis including, for instance, $K\pi$ s-wave effects.

One should note that the small cross section obtained for $K^{*0}(892)K_S^0$ production from reaction (4) seems to be related to the positive C-parity of the final state. The cross section for the same channel but related to the negative C-parity:

$$\bar{p}p \rightarrow K^{*0}(892)K_S^0, \quad K^{*0}(892) \rightarrow K_L^0\pi^0.$$

can be deduced from the reaction

$$\bar{p}p \rightarrow K_S^0 M \tag{5}$$

where M represents a missing mass compatible with a missing $K^0\pi^0$ system. Fig. 10 shows this missing mass distribution, the events fitting reaction (2) being included. A clear $K^*(892)$ is observed in the missing mass spectrum, corresponding to a cross section of 54 ± 3 μb for the process

$$\bar{p}p \rightarrow K^{*0}(892)K_S^0 \rightarrow K_S^0 K_L^0 \pi^0$$

FOUR-BODY ANNIHILATIONS $\bar{p}p \rightarrow K\bar{K}\pi\pi$

We observe the following four-body annihilation reactions:

$$\bar{p}p \rightarrow K_S^0 K_S^0 \pi^+ \pi^- \tag{6}$$

$$\bar{p}p \rightarrow K_S^0 (K^0) \pi^+ \pi^- \tag{7}$$

$$\bar{p}p \rightarrow K_S^0 K^\pm \pi^\mp \pi^0. \tag{8}$$

The cross sections measured for these reactions are given in table 4.

Figs 11-13 show the two-body and three-body effective masses which can be formed for these reactions. One observes not only a large production of $K^*(892)$ but also the presence of $S^*(980)$, $\phi(1020)$, $A_2(1310)$ and $\rho(770)$.

To obtain a quantitative estimate of these resonance productions, we have performed a simultaneous fit of all the effective mass spectra, for each channel, assuming that the transition amplitudes take the form

$$A_i = P_i \cdot f \cdot D_i$$

where P_i expresses the production properties of the intermediate channel, D_i its decay properties. f takes the general form

$$f = \frac{1}{2p_i} (e^{2i\delta_i} - 1)$$

where p_i is the momentum of the system characterized by the phase shift δ_i . In the present analysis f has been approximated by the Breit-Wigner distributions,

$$f = \frac{m_R \Gamma_R^0}{m_R^2 - m^2 - im_R \Gamma_R} \left(\frac{q}{q_R} \right)$$

$$\Gamma_R = \Gamma_R^0 \frac{m_R}{m} \left(\frac{q}{q_R} \right)^{2l+1}$$

where m_R , Γ_R^0 and q_R represent the mass, width and 3 the modulus of the momentum of the decay products of the resonance, respectively; l is the orbital angular momentum between the decay products, m and q are the actual effective mass and the momentum characteristic of a given event.

P_i and D_i are taken as constant in the present analysis, the production and decay angular distributions having no significant reflection on the fitted mass spectra.

Having defined as many transition amplitude A_i as necessary to reproduce the main structures observed in the mass spectra, we add them incoherently to form the square of the total transition amplitude

$$A^2 = \sum_i w_i |A_i|^2 ,$$

w_i giving then the relative contribution of the intermediate channel i .

The free parameters w_i have been determined by maximum likelihood fits, in which the masses and widths of the resonances are fixed to the values given in table 8. The results of these fits are given in table 9 and their projections on the mass spectra are represented by the continuous curves on figs 11-13. The cross sections in table 9 are corrected for the branching ratios of the resonances observed in the final state. For the $S^*(980)$ and $\delta(980)$, we take only into account their $K\bar{K}$ decay mode. For the $(A^2 + f)$ complex, we assume a mean branching ratio into $K\bar{K}$ of 3.5%.

Even with such a simple model, one sees that four-body phase space is limited to $\sim 10\%$, the quasi two-body and three-body intermediate channels dominating these annihilations. By and large, the $K^*(892)$ production dominates all three reactions. In particular, the quasi two-body process

$$\bar{p}p \rightarrow K^* \bar{K}^*$$

contributes to nearly one third of reactions (6) and (7). Fig. 14 shows the production angular distribution of the K^{*-} and $\bar{K}^{*0}$ for the 4-body reactions where the strangeness of the K^* is defined. Whereas the K^{*0} distribution is compatible with isotropy, one notes a significant anisotropy and asymmetry for the K^{*-} one.

In contrast to the $K^*(892)$, the $\rho(770)$ production is relatively small, being completely negligible for the three-body channel $KK\rho^0$. Phase space factors cannot completely explain these suppressions since the channel $K_S^0 K^\pm \rho^\mp$ still represents 13% of reaction (8).

It may be mentioned that the production of $S^*(980)$, $\phi(1020)$ and $A_2(1310)$ is significant; a large fraction of these result from the quasi-two-body processes where the $S^*(980)$, $\phi(1020)$ and $A_2(1310)$

are produced in association with a $\rho(770)$ meson. This is also the case for the $f^0(1270)$ and the $A_2^0(1310)$ which cannot be separated and are therefore introduced simultaneously in the fit with the effective mass and width given in table 8.

Finally, several $K\bar{K}\pi$ resonances have been introduced in this analysis. For the $I = 0$ system, three resonances have been considered. The $D(1285)$ and $E(1420)$, since previous observations [11,12] have suggested their presence in reaction (8), and the $f'(1515)$, since the two-body annihilations $pp \rightarrow f'\pi^0$, with $f' \rightarrow K_S^0 K_S^0$ contribute significantly to reaction (4). Our analysis shows that none of these $K\bar{K}\pi$ resonances has a significant contribution to reaction (8).

In addition to the $I = 0$ $K\bar{K}\pi$ resonances, we have considered the possibility that an $I = 1$ $K\bar{K}\pi$ resonance is present in reaction (7), the $F_1(1540)$. This resonance has been proposed, [13,14], to explain the $\bar{K}K\pi$ mass spectrum in $\bar{p}p$ annihilations at 702 MeV/c. These original data are included in the present analysis. Since the new data, obtained at a slightly different incident momentum (757 MeV/c), do not show the same effect, with nearly four times the statistics, the evidence for the $F_1(1540)$ resonance becomes non-significant in the combined data. A detailed analysis has been achieved to clarify this discrepancy between the old and new data (sect. 7). Our conclusion is that the effect observed in the old data is probably due to systematic effects due to ambiguous events in the original analysis.

The observation of a $K_S^0 K_S^0$ threshold enhancement in reaction (6), the $S^*(980)$, has been used in a previous publication to investigate the $I = 0$ $J^{PC} = 0^{++}$ $K\bar{K} \rightarrow K\bar{K}$ amplitude [15]. In this publication, it was shown that a coupled channel parametrization for the $I = 0$ s-wave which takes into account the analytical structure of this wave can fit simultaneously the $K_S^0 K_S^0$ mass spectrum in the threshold region and the $\pi\pi$ phase shift and inelasticity measured by Hyams et al. [16]. It was found that the unphysical Riemann sheets have poles which can be associated to the S^* resonance, the resonance parameters being $m_0 = 1040 \pm 6$ MeV and $\Gamma_0 = 65 \pm 14$ MeV.

The $\phi(1020)$ meson, as observed in reaction (7) has been compared in [17] to the $\omega(783)$ production. It was found that the ratio $\sigma(pp \rightarrow \phi\pi^+\pi^-)/\sigma(pp \rightarrow \omega\pi^+\pi^-)$, where the final states $\phi\pi^+\pi^-$ and $\omega\pi^+\pi^-$ do not include ρ^0 in the $\pi^+\pi^-$ combination, is $(10 \pm 2.4) \times 10^{-3}$ and becomes $(19 \pm 5) \times 10^{-3}$ when corrected for the phase space factor. Similarly, it was found that $\sigma(\bar{p}p \rightarrow \phi\rho^0)/\sigma(\bar{p}p \rightarrow \omega\rho^0)$ is $(9.0 \pm 3.0) \times 10^{-3}$, becoming $(13 \pm 4) \times 10^{-3}$ when corrected for phase space. These ratios indicate the presence of a dynamical violation of the Okubo-Zweig-Iizuka rule, the degree of violation lying between 5% and 22%.

The cross sections obtained for the resonance productions at 700-760 MeV/c incident momenta are not much different from those obtained at 1.2 GeV/c [3,18]. This is particularly true for the "global" production of $K^*(892)$, $\rho(770)$, $S^*(980)$, $\phi(1020)$ and $A_2(1310)$. This similarity between 700-760 MeV/c and 1.2 GeV/c can be contrasted to the striking differences observed with annihilations at rest (1).

7. THE $F_1(1540)$

As mentioned in the previous section, there is a clear disagreement between the observation of an enhancement in the $K_s^0(K_s^0)\pi^\pm$ effective mass spectrum, named $F_1(1540)$, at 702 MeV/c and the absence of such an enhancement in the 757 MeV/c data. We proceed now to a comparative study of these data and show that the difference cannot be attributed to the small incident momentum difference, but rather to a contamination of the 702 MeV/c data which was not correctly treated in the previous analysis [13,14].

In fig. 15, histograms (a) show the $(K\bar{K}\pi)^\pm$ effective mass squared distribution for the final state

$$\bar{p}p \rightarrow K^0\bar{K}^0\pi^+\pi^-$$

i.e. for reactions (6) and (7) combined. The $F_1(1540)$ enhancement appears clearly in the 702 MeV/c data, and does not show up at 757 MeV/c. Quantitatively, and fitting the $K\bar{K}\pi$ enhancement with a Breit-Wigner distribution with $M = 1540$ MeV, $\Gamma = 40$ MeV, one finds

$$\sigma(\bar{p}p \rightarrow F_1^\pm \pi^\mp) = 50 \pm 13 \text{ } \mu\text{b at } 702 \text{ MeV/c}$$

$$\sigma(\bar{p}p \rightarrow F_1^\pm \pi^\mp) = 6.5 \pm 6.7 \text{ } \mu\text{b at } 757 \text{ MeV/c.}$$

The cross section at the higher momentum is consistent with zero and is in clear disagreement with the 702 MeV/c value.

For completeness we also show in fig. 15 the $K\bar{K}\pi$ effective mass squared distributions, for the same final state, after imposing the selections defined in ref. [14] which enhance the $F_1(1540)$ signal. First, events located in the phase space region dominated by double K^* production are removed, shown as (b) in the figure. Then, from this selected sample, only the combinations having at least a $K\pi$ system in the $K^*(890)$ region (0.84 - 0.94 GeV) are plotted, shown as (c) in the figure. Again, a striking difference between the two sets of data is observed.

The main evidence for the $F_1(1540)$ at 702 MeV/c comes from reaction (7), which is known to present large ambiguities with reaction (8). At 757 MeV the fraction of ambiguities between the $K^0(K^0)\pi^+\pi^-$ and the $K^0K^\pm\pi^\mp\pi^0$, ($K^0K^\pm\pi^\mp M$) hypotheses is 21% (3%) of the events unambiguously assigned to the $\bar{p}p \rightarrow K_S^0(K^0)\pi^+\pi^-$ channel. This large percentage of ambiguities can be a possible source of important systematic effects since the identification procedure followed at 702 MeV/c was not identical to that followed at 757 MeV/c.

At 702 MeV/c the $F_1(1540)$ signal seems to be associated with those $\bar{p}p \rightarrow K_S^0(K^0)\pi^+\pi^-$ events for which an identification error due to an ionization ambiguity may occur. We define the ionization

$$I_{K,\pi} = \left(1 + \frac{m_{K/\pi}^2}{p^2}\right) \frac{1}{\cos\lambda}$$

where $m_{K/\pi}$ is the kaon/pion mass, p is the momentum of the track whose mass assignment is artificially changed from the pion into the kaon mass and λ is the dip angle. In order to visualize a possible contamination effect, we have divided the sample for reaction (7) at 702 MeV/c (fig. 16(a)) into the subsamples c and d by requiring $I_K < 2.5$ or

$I_{\pi} > 3$, $I_k > 2.5$ and $I_{\pi} < 3$ respectively. It can be seen from fig. 16(c) and (d) that the $F_1(1540)$ is mainly associated with those events which can be ambiguous, from the ionization information, between reactions (7) and (8).

In order to further investigate this ambiguity the subsample c was divided into two groups of events, e and f. These groups shown in figs. 16(e) and (f) contain the events which have a non-unique kinematical interpretation. The subsample e (f) selects (antiselects) the events for which replacing the pion mass by the kaon mass in one of the charged tracks leads to a missing mass compatible with a π^0 (the compatibility interval was chosen to be $|M_{\pi^0}^2 - 1.5 \sigma, M_{\pi^0}^2 + 1.5 \sigma| = |-0.010 \text{ GeV}^2, 0.046 \text{ GeV}^2|$, 2σ being the FWHM of the MM^2 distribution for those events unambiguously assigned to the final state $\bar{p}p \rightarrow K_S^0 K^{\pm} \pi^{\mp} \pi^0$). The enhancement is mainly observed among those events which are kinematically ambiguous between the channels 7 and 8.

The distributions displayed in figs 16(e,f) include two $K\bar{K}\pi$ combinations per event. However, assuming an identification bias, it seems plausible that the $F_1(1540)$ will be mainly associated with the $K\bar{K}$ combinations which are, in the original and correct interpretation, $K\pi\pi$ combinations and not $K\bar{K}\pi$ combinations. Figs 16(g) and 16(h) show the $K_S^0(K^0)\pi^{\pm}$ mass squared distributions for the subsample e and for the combinations which are either $K\pi\pi$ (g) or $K\bar{K}\pi$ (h) in the corresponding ambiguous hypothesis. As can be seen, the F_1 is mainly associated with the $K\pi\pi$ combinations. Going back to the original sample (fig. 16(a)), and removing the sample corresponding to fig. 16(e), we get fig. 16(b) which does not show a significant $F_1(1540)$.

These observations were confirmed with the 757 MeV/c data. Using a sample ($\approx 30\%$) of the events which at the identification stage were classified as ambiguous between reactions (7) and (8), we have assigned all of them to the reaction $\bar{p}p \rightarrow K_S^0(K^0)\pi^+\pi^-$. Again, an enhancement in the $F_1(1540)$ region of the $K\bar{K}\pi$ mass distribution was artificially produced (fig. 17(a)). Figs 17(c) and 17(d) show the result of applying the criteria explained above to the ambiguous sample. The enhancement is present in $KK\pi$ combination recoiling to the ambiguous particle.

Finally, figs 17(e) and 17(f) show a division of fig. 17(a) into two subsamples, which correspond to the events for which the χ^2 probability is larger for reactions (8) or (7) respectively. The enhancement is present mainly in the subsample which has a large probability to be a $K_s^{\pm} K^0 \pi^{\mp} \pi^0$ final state.

The assumption that misidentification can be at the origin of the $F_1(1540)$ was also checked by a Monte-Carlo generation of events. We have generated $\bar{p}p \rightarrow K_s^0 K^{\pm} \pi^{\mp} \pi^0$ phase space events and replaced the charged kaon mass by the pion one. The $K\bar{K}\pi$ mass squared distribution is presented in fig. 17(b) for the events satisfying the conditions leading to a kinematical ambiguity ($0.206 \text{ GeV}^2 < M^2 < 0.290 \text{ GeV}^2$) and a ionization ambiguity. The distribution exhibits a clear peak in the $F_1(1540)$ region. The discrepancy (factor 2) between the widths of the "real" and Monte-Carlo effects may be due to the crudeness of this model.

We conclude that the $F_1(1540)$ signal is a consequence of a systematic bias in the 702 MeV/c data.

8. FIVE-BODY ANNIHILATIONS $\bar{p}p \rightarrow K\bar{K}\pi\pi\pi$

We observe the following five-body annihilation reactions:

$$\bar{p}p \rightarrow K_s^0 K^{\pm} \pi^{\mp} \pi^+ \pi^- \quad (9)$$

$$\bar{p}p \rightarrow K_s^0 K_s^0 \pi^+ \pi^- \pi^0 \quad (10)$$

The cross sections for these reactions are given in table 4. A detailed analysis has already been presented [19] and we shall limit here to a summary of the results.

Reaction (9) is dominated by $K^*(892)$ production. In contrast to the four-body annihilations, however, there is very little, if any, double $K^*(892)$ production, but, instead, the associated production of a $K^*(892)$ and of a $\rho(770)$ is important. The main difference with four-body annihilations is the sizeable production of $D(1285)$ and $E(1420)$ mesons, [19] representing 16% and 19%, respectively, of reaction (9).

Fig. 18 shows the $K_S^0 K^\pm \pi^\mp$ mass spectrum with its two enhancements corresponding to the D(1285) and E(1420) mesons.

Reaction (10) is dominated by $\omega(783)$ production (fig. 19). In addition, small contributions from $K^*(892)$, $\delta(980)$ and D(1285) mesons are detected.

Table 10 gives the results of the channel maximum likelihood analyses.

As for the four-body annihilations, the similarity between these results and those obtained at 1.2 GeV/C [3,18] is remarkable, in contrast to the comparison with $\bar{p}p$ annihilations at rest [20], which do not show any evidence for D(1285) production, whereas the E(1420) production dominates the five-body annihilation reaction (9).

9. SIX-BODY ANNIHILATIONS $\bar{p}p \rightarrow K\bar{K}\pi\pi\pi\pi$

We observe the following six-body annihilation reactions

$$\bar{p}p \rightarrow K_S^0 K^\pm \pi^\mp \pi^+ \pi^- \pi^0 \quad (11)$$

$$\bar{p}p \rightarrow K_S^0 \pi^+ \pi^+ \pi^- \pi^- (K^0) . \quad (12)$$

The cross sections for these reactions are given in table 4.

There is no significant $K^*(892)$ production in reaction (11), and the main contributions to the final state are associated to the $\delta(890)$ meson. The results of the channel likelihood fit, where the δ has been parametrized as the scattering length amplitude of 2.5 fm [19], appear in table 11.

Fig. 20 shows the $K_S^0 K^\pm$ and $\pi^+ \pi^- \pi^0$ spectra for this reaction. The solid lines correspond to the result of the channel likelihood fit.

10. ANNIHILATIONS WITH MORE THAN ONE MISSING NEUTRAL PARTICLE

A small fraction of our data corresponds to annihilations with more than one missing neutral particle. They are included in table 4 with a label M in the final state.

We have already discussed the reaction

$$\bar{p}p \rightarrow K_S^0 M \quad (5)$$

when discussing the production of $K^*(892)$ in three-body annihilations (sect. 5 and fig. 10).

The next reaction to be shortly discussed is

$$\bar{p}p \rightarrow K_S^0 K_S^0 M. \quad (13)$$

Fig. 21 shows the missing mass spectrum for this reaction. Clear peaks are observed at the η^0 and ω^0 masses. Compared to the $(\pi^+ \pi^- \pi^0)$ mass spectrum of reaction (10), (fig. 20) they agree with the known branching ratios of these resonances.

Excluding η^0 and ω^0 production, we find a total cross section of $40 \pm 5 \mu\text{b}$ for 4 and 5-body annihilations which include a pair of K_S^0 and 2 or 3 π^0 's. It is remarkably small compared to other 4 and 5-body annihilations. This observation may be paralleled to the two-body annihilations $\bar{p}p \rightarrow K_S^0 K_S^0$ and $\bar{p}p \rightarrow K_S^0 K_L^0$, where the final state with $C = +1$ is also much weaker than the one with $C = -1$.

The missing mass spectrum of the reaction

$$\bar{p}p \rightarrow K_S^0 K^{\pm} \pi^{\mp} M, \quad (14)$$

fig. 22, suggests the presence of η^0 in this final state. This is in agreement with the results of the analysis of reaction (11), a large fraction of which is attributed to $\delta^{\pm} \pi^{\mp} \eta^0$ (table 11). Another feature of reaction (14) is the presence of the D(1285) meson in the $K_S^0 K^{\pm} \pi^{\mp}$ effective mass spectrum [19], the process

$$\bar{p}p \rightarrow D^0 M,$$

corresponding to a cross section of $12 \pm 3 \mu\text{b}$.

Finally, the reaction

$$\bar{p}p \rightarrow K_S^0 \pi^+ \pi^- M \quad (15)$$

for which the production cross sections at 702 and 757 MeV/c are given in table 4, does not present any particular feature.

11. QUASI TWO-BODY ANNIHILATIONS

The information obtained about the quasi two-body reactions cross sections is grouped in table 12. The cross sections have been corrected for the unobserved decay modes of the resonances.

12. INCLUSIVE PRODUCTION OF $K^*(892)$ and K_S^0

The inclusive production of K^* and K_S^0 have been discussed in ref. [21]. It was found that $(30 \pm 2)\%$ of all K_S^0 are indirectly produced through the decay of $K^*(892)$. Including the contribution of all other resonances it was deduced that $(50 \pm 5)\%$ of all K_S^0 are indirectly produced through the decay of meson resonances.

13. CONCLUSIONS

The analysis of proton-antiproton annihilations into strange particles and pions at 702 and 757 MeV/c reveals a series of facts which seem to be specific of the annihilation mechanism. In general, the properties observed at 702 and 757 MeV/c are in agreement with those observed for $\bar{p}p$ annihilations in flight, at low incident momentum, but they are often very different from the properties of $\bar{p}p$ annihilations at rest.

The $K^*(892)$ production is important in these annihilations, and the double production of $K^*(892)$ is particularly important at 700-750 MeV/c.

The dominance of $C = -1$ final states over $C = +1$ is striking, although the explanation given for annihilations at rest does not automatically apply here.

The production of D(1285) and E(1420) mesons are significant in 5-body annihilations, in contrast to the annihilations at rest, where the D(1285) is absent and the E(1420) production is important. This is reminiscent of the observation made on the radiative decay of the $J\psi$, where a $K\bar{K}\pi$ enhancement is observed with a mass and a width closed to those attributed to the E(1420), but where no D(1285) meson is observed. Annihilations in flight are more similar to the hadronic reactions, i.e. $\pi^- p$ [22], where both the D(1285) and the E(1420) are observed.

The $\delta(980)$ and $S^*(980)$ are observed in several channels. The $S^*(980)$ signal has been used, together with the $\pi\pi$ phase shifts and inelasticities to get additional information on the $K\bar{K} \rightarrow K\bar{K}$ amplitude [15].

A large fraction ($\sim 90\%$) of 3, 4, 5 and 6-body final states result from annihilations into quasi-two and three-body. The $K\bar{K}\pi$ structure considered previously as an evidence for the existence of the F_1 meson has been shown to be the consequence of systematic biases.

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TABLE CAPTIONS

- Table 1 Sensitivity and beam conditions of this experiment.
- Table 2 Statistics for $\bar{p}p \rightarrow K_S^0 K_S^0$ and $p\bar{p} \rightarrow K_S^0(K^0)$.
- Table 3 Topological cross sections for annihilations with one or two $K_S^0 \rightarrow \pi^+ \pi^-$ decays, at 757 MeV/c incident momentum. N_c is the number of charged particles associated to the annihilation. N_v is the number of $K_S^0 \rightarrow \pi^+ \pi^-$.
- Table 4 Channel annihilation cross sections. The notation is the following: K_S^0 is for a K_S^0 decay, including unobservable decay modes. K_L^0 is for all K_L^0 decays and (K^0) is for unobservable K^0 (K_S^0 or K_L^0). M is for at least two missing neutral particles.
- Table 5 $\bar{p}p \rightarrow K_S^0 K_L^0$. Legendre polynomial coefficients.
- Table 6 $\bar{p}p \rightarrow K_S^0 K^\pm \pi^\mp$. Channel analysis and partial cross sections.
- Table 7 Legendre coefficients for quasi two-body annihilations observed in $\bar{p}p \rightarrow K^0 K^\pm \pi^\mp$ at 757 MeV/c.
- Table 8 Mass, width and decay mode of resonances introduced in the analysis.
- Table 9 $\bar{p}p \rightarrow K\bar{K}\pi\pi$. Channel analysis and partial cross sections.
- Table 10 $\bar{p}p \rightarrow K_S^0 K^\pm \pi^\mp \pi^+ \pi^-$ and $\bar{p}p \rightarrow K_S^0 K_S^0 \pi^+ \pi^- \pi^0$. Channel analysis and partial cross sections.
- Table 11 Resonance production in $\bar{p}p \rightarrow K_S^0 K^\pm \pi^\pm \pi^+ \pi^- \pi^0$.
- Table 12 Quasi two-body cross sections.

TABLE 1

Exposure	Sensitivity	Average beam momentum MeV/c	Momentum dispersion MeV/c
1	6 evt/ μ b	702	23
2	22 evt/ μ b	757	13

TABLE 2

Average beam momentum MeV/c	No. of events		Reference
	$K_S^0 K_S^0$	$K_S^0 (K^0)$	
370	0	31	[2]
430	0	40	
460	0	30	
557	0	14	
618	2	14	
825	0	5	
905	1	8	
1000	2	4	
1042	1	7	
1127	0	6	
1170	16	66	[3]
702	4	125	This experiment
757	28	402	

TABLE 3

N_c	N_v	Cross section (μb)
0	1	185.2 ± 9.8
0	2	57.5 ± 4.7
2	1	1167.4 ± 40.0
2	2	166.7 ± 10.0
4	1	72.7 ± 5.4
6	1	0.6 ± 0.3
Total		1650.1 ± 43.0

TABLE 4

Final state	Cross sections (μb)	
	702 MeV/c	757 MeV/c
$K_S^0(K^0)$	45 ± 6	31 ± 3
$K_S^0 K_L^0$	44 ± 7	28 ± 3
$K_S^0 M$	282 ± 20	247 ± 11
$K_S^0 K_S^0$	1.7 ± 1.1	3.0 ± 0.7
$K_S^0 K_S^0 \pi^0$	66 ± 9	54 ± 4
$K_S^0 K_S^0 M$	81 ± 10	63 ± 5
$K_S^0 K^\pm \pi^\mp$	552 ± 31	433 ± 10
$K_S^0 K^\pm \pi^\mp \pi^0$	720 ± 38	615 ± 13
$K_S^0 K^\pm \pi^\mp M$	55 ± 22	60 ± 3
$K_S^0 \pi^+ \pi^- (K^0)$	568 ± 25	450 ± 13
$K_S^0 \pi^+ \pi^- K_L^0$	377 ± 27	272 ± 16
$K_S^0 \pi^+ \pi^- M$	126 ± 15	156 ± 7
$K_S^0 K_S^0 \pi^+ \pi^-$	237 ± 20	216 ± 11
$K_S^0 K_S^0 \pi^+ \pi^- \pi^0$	173 ± 17	139 ± 8
$K_S^0 K_S^0 \pi^+ \pi^- M$	1.7 ± 1.1	4 ± 1
$K_S^0 K^\pm \pi^\mp \pi^+ \pi^-$	100 ± 12	100 ± 5
$K_S^0 K^\pm \pi^\mp \pi^+ \pi^- \pi^0$	10 ± 3	7 ± 1
$K_S^0 \pi^+ \pi^+ \pi^- \pi^- (K^0)$	0 ± 0.6	0.9 ± 0.4
$K_S^0 K^\pm \pi^\mp \pi^+ \pi^- M$	2 ± 1.2	1.1 ± 0.5

TABLE 5

	Antiproton momentum (MeV/c)									
	370	430	460	570	702	757	980	1170		
a_2/a_0	1.4 ± 0.4	1.3 ± 0.3	1.7 ± 0.4	1.5 ± 0.3	$.7 \pm .2$	$1.4 \pm .8$	$.7 \pm .4$	$.4 \pm .3$		
a_4/a_0	$-.2 \pm .6$	$-.4 \pm .6$	$-1.3 \pm .6$	$-1.3 \pm .6$	$-.9 \pm .2$	$-1.2 \pm .2$	$-1.3 \pm .6$	$-.5 \pm .4$		
a_6/a_0	$.2 \pm .6$	$-.2 \pm .7$	$-1.9 \pm .7$	-2.3 ± 1.1	$-.9 \pm .3$	$-.4 \pm .2$	$-.5 \pm .6$	$-.7 \pm .5$		
a_8/a_0	-	-	-	-	-	$-.3 \pm .2$	-	-		
χ^2/ND	5.8/4	14./5	3.3/3	6./5	4.7/6	8.8/6	9.2/5	6.6/5		

TABLE 6

	Fraction (%)		Cross sections (μb)	
	702 MeV/c	757 MeV/c	702 MeV/c	757 MeV/c
$K^{*\pm}(892)K^{\mp}$	$0.27 \pm .03$	0.30 ± 0.02	447 ± 30	380 ± 20
$K^{*0}(892)K_S^0$	0.22 ± 0.03	0.20 ± 0.02	182 ± 10	130 ± 10
$A_2^{\pm}(1310)\pi^{\mp}$	0.12 ± 0.02	0.13 ± 0.02	2818 ± 200	2780 ± 190
$K^{*\pm}(1420)K^{\mp}$	0.03 ± 0.01	0.03 ± 0.01	100 ± 20	77 ± 12
$K^{*0}(1420)K_S^0$	0.09 ± 0.03	0.07 ± 0.02	149 ± 15	91 ± 9
$(K\pi)^0 s\text{-wave}^{\pm}$	0.01 ± 0.01	0.00 ± 0.01	17 ± 5	0 ± 5
$(K\pi)^0 s\text{-wave}$	0.26 ± 0.02	0.22 ± 0.02	215 ± 20	144 ± 15
Phase space	0.00 ± 0.02	0.05 ± 0.02	0 ± 15	22 ± 15
Density matrix elements				
$\rho_{00}(K^{*\pm})$	0.33 ± 0.03	0.33 ± 0.02		
$\rho_{00}(K^{*0})$	0.36 ± 0.03	0.29 ± 0.02		
$\rho_{11}(A_2^{\pm})$	0.23 ± 0.03	0.10 ± 0.02		
$\rho_{22}(A_2)^{\pm}$	0.26 ± 0.03	0.27 ± 0.02		

TABLE 7

	$K^{*\pm}(892)K^{\mp}$	$K^{*0}(892)K_S^0$	$A^{\pm}(1310)$
a_1/a_0	0.34 ± 0.00	0.19 ± 0.10	-0.24 ± 0.24
a_2/a_0	0.52 ± 0.10	-0.28 ± 0.15	0.52 ± 0.32
a_3/a_0	-0.82 ± 0.13	0.00 ± 0.16	-0.78 ± 0.41
a_4/a_0	-0.44 ± 0.17	-0.19 ± 0.20	-
a_5/a_0	0.38 ± 0.18	0.72 ± 0.30	-

TABLE 8

Resonance	m_R (MeV)	Γ_R^0 (MeV)	Decay modes
$\rho(770)$	773	152	$\pi\pi$
$K^{*\pm}(892)$	893.1	55	$K\pi$
$K^{*0}(892)$	898.6	55	$K\pi$
$\delta(980)$	980	50	$K\bar{K}$
$\phi(1020)$	1019.5	4.5	$K_S^0 K_L^0$
$S^*(980)$	1040.3	40	$\bar{K}K$
$D(1285)$	1285	30	$K\bar{K}\pi$
$A_2(1310)$	1310	102	$K\bar{K}$
$E(1420)$	1417.5	45	$K\bar{K}\pi$
$f'(1515)$	1516	40	$K\bar{K}\pi$
$F_1(1540)$	1540	40	$K\bar{K}\pi$
$f + A_2$	1285	120	$K\bar{K}$

TABLE 9

Channel	fractions	Cross sections (μb)
$\bar{p}p \rightarrow K_S^0 K_S^0 \pi^+ \pi^-$ (6)		
$K^{*+} K_S^0 \pi^-$	0.18 ± 0.03	120 ± 18
$K^{*-} K_S^0 \pi^+$	0.15 ± 0.03	100 ± 15
$K^{*+} K^{*-}$	0.28 ± 0.03	560 ± 50
$K_S^0 K_S^0 \rho^0$	0.007 ± 0.007	1.5 ± 1.5
$S^* \pi^+ \pi^-$	0.05 ± 0.02	45 ± 12
$S^* \rho^0$	0.04 ± 0.02	36 ± 10
$(f + A_2) \pi^+ \pi^-$	0.10 ± 0.02	2250 ± 400
$(f + A_2) \rho^0$	0.09 ± 0.02	2170 ± 400
Phase space	0.10 ± 0.02	25 ± 10
$\bar{p}p \rightarrow K_S^0 (K^0) \pi^+ \pi^-$ (7)		
$K^{*+} K^0 \pi^-$	0.185 ± 0.02	250 ± 20
$K^{*-} K^0 \pi^+$	0.21 ± 0.02	285 ± 20
$K^{*+} K^{*-}$	0.30 ± 0.02	615 ± 40
$\phi \pi^+ \pi^-$	0.04 ± 0.01	53 ± 15
$\phi \rho^0$	0.02 ± 0.01	26 ± 10
$F_1^\pm \pi^\mp$	0.014 ± 0.01	38 ± 26
$(f + A_2) \pi^+ \pi^-$	0.016 ± 0.01	845 ± 425
$(f + A_2) \rho^0$	0.08 ± 0.01	4230 ± 500
Phase space	0.13 ± 0.02	62 ± 10

TABLE 7

	$K^{*\pm}(892)K^{\mp}$	$K^{*0}(892)K_S^0$	$A^{\pm}(1310)$
a_1/a_0	0.34 ± 0.00	0.19 ± 0.10	-0.24 ± 0.24
a_2/a_0	0.52 ± 0.10	-0.28 ± 0.15	0.52 ± 0.32
a_3/a_0	-0.82 ± 0.13	0.00 ± 0.16	-0.78 ± 0.41
a_4/a_0	-0.44 ± 0.17	-0.19 ± 0.20	-
a_5/a_0	0.38 ± 0.18	0.72 ± 0.30	-

TABLE 8

Resonance	m_R (MeV)	Γ_R^0 (MeV)	Decay modes
$\rho(770)$	773	152	$\pi\pi$
$K^{*\pm}(892)$	893.1	55	$K\pi$
$K^{*0}(892)$	898.6	55	$K\pi$
$\delta(980)$	980	50	$K\bar{K}$
$\varphi(1020)$	1019.5	4.5	$K_S^0 K_L^0$
$S^*(980)$	1040.3	40	$\bar{K}K$
$D(1285)$	1285	30	$K\bar{K}\pi$
$A_2(1310)$	1310	102	$K\bar{K}$
$E(1420)$	1417.5	45	$K\bar{K}\pi$
$f'(1515)$	1516	40	$K\bar{K}\pi$
$F_1(1540)$	1540	40	$K\bar{K}\pi$
$f + A_2$	1285	120	$K\bar{K}$

TABLE 9

Channel	fractions	Cross sections (μb)
$\bar{p}p \rightarrow K_S^0 K_S^0 \pi^+ \pi^-$ (6)		
$K^{*+} K_S^0 \pi^-$	0.18 ± 0.03	120 ± 18
$K^{*-} K_S^0 \pi^+$	0.15 ± 0.03	100 ± 15
$K^{*+} K^{*-}$	0.28 ± 0.03	560 ± 50
$K_S^0 K_S^0 \rho^0$	0.007 ± 0.007	1.5 ± 1.5
$S^* \pi^+ \pi^-$	0.05 ± 0.02	45 ± 12
$S^* \rho^0$	0.04 ± 0.02	36 ± 10
$(f + A_2) \pi^+ \pi^-$	0.10 ± 0.02	2250 ± 400
$(f + A_2) \rho^0$	0.09 ± 0.02	2170 ± 400
Phase space	0.10 ± 0.02	25 ± 10
$\bar{p}p \rightarrow K_S^0 (K^0) \pi^+ \pi^-$ (7)		
$K^{*+} K^0 \pi^-$	0.185 ± 0.02	250 ± 20
$K^{*-} K^0 \pi^+$	0.21 ± 0.02	285 ± 20
$K^{*+} K^{*-}$	0.30 ± 0.02	615 ± 40
$\varphi \pi^+ \pi^-$	0.04 ± 0.01	53 ± 15
$\varphi \rho^0$	0.02 ± 0.01	26 ± 10
$F_1^\pm \pi^\mp$	0.014 ± 0.01	38 ± 26
$(f + A_2) \pi^+ \pi^-$	0.016 ± 0.01	845 ± 425
$(f + A_2) \rho^0$	0.08 ± 0.01	4230 ± 500
Phase space	0.13 ± 0.02	62 ± 10

TABLE 9 (Cont'd)

Channel	fractions	Cross sections (μb)
$\bar{p}p \rightarrow K_S^0 K^\pm \pi^\mp \pi^0$ (8)		
$K^{*\pm} K^\mp \pi^0$	0.11 ± 0.01	220 ± 20
$K^{*0} K_S^0 \pi^0$	0.07 ± 0.01	70 ± 10
$K^{*0} K^\pm \pi^\mp$	0.06 ± 0.01	240 ± 40
$K^{*\pm} K_S^0 \pi^\mp$	0.10 ± 0.01	205 ± 20
$K^{*+} K^{*-}$	0.17 ± 0.01	535 ± 30
$K^{*0} \bar{K}^{*0}$	0.06 ± 0.01	180 ± 25
$K_S^0 K^\pm \rho^\mp$	0.13 ± 0.02	87 ± 10
$A_2^\pm \pi^\mp \pi^0$	0.04 ± 0.01	1140 ± 200
$A_2^\pm \rho^\mp$	0.05 ± 0.01	1430 ± 260
$\phi^\pm \pi^\mp \pi^0$	0.08 ± 0.01	106 ± 12
$D\pi^0$	0.01 ± 0.01	20 ± 10
$E\pi^0$	0.02 ± 0.01	40 ± 20
$f'\pi^0$	0.02 ± 0.01	13 ± 5
Phase space	0.09 ± 0.02	60 ± 10

TABLE 10

Channel	Fraction	Cross section (μb)
$K^* K \pi \pi$	0.08 ± 0.05	25 ± 15
$K^* K \rho$	0.39 ± 0.05	120 ± 17
$K_s^0 K^\pm \pi^\mp \rho^0$	0.08 ± 0.03	8 ± 3
$A_2^\pm \rho^0 \pi^\mp$	0.05 ± 0.01	220 ± 50
$D^0 \pi^+ \pi^-$	0.11 ± 0.02	34 ± 10
$D^0 \rho^0$	0.05 ± 0.02	20 ± 5
$E^0 \pi^+ \pi^-$	0.19 ± 0.05	60 ± 15
Phase space	0.06 ± 0.04	6 ± 4
$K_s^0 K_s^0 \omega^0$	0.59 ± 0.03	104 ± 4
$\delta \rho \pi$	0.11 ± 0.02	70 ± 8
$K^* K \pi \pi$	0.06 ± 0.02	30 ± 15
$K^* K \rho$	0.12 ± 0.03	58 ± 12
$A_2 \rho \pi$	0.03 ± 0.01	400 ± 100
$D^0 \pi^+ \pi^-$	0.03 ± 0.015	58 ± 20
$D^0 \rho^0$	0.02 ± 0.01	38 ± 10
$E^0 \pi^+ \pi^-$	0.04 ± 0.025	76 ± 40

TABLE 11

Channel	Fraction	Cross section (μb)
$\delta^\pm \pi^\mp \omega^0$	0.40 ± 0.10	9 ± 3
$\delta^\pm \pi^\mp \eta^0$	0.22 ± 0.05	19 ± 6
$\delta^\pm \pi^\mp \pi^+ \pi^- \pi^0$	0.15 ± 0.005	3 ± 2
Phase space	0.23 ± 0.05	3 ± 1

TABLE 12

Reaction	Observed resonance decay mode	Branching ratio applied	$\sigma(\mu\text{b})$
$K^{*\pm}(892)K^{\mp}$	$K_S^0\pi^{\pm}$	0.33	400 ± 40
$K^{*0}(892)K_S^0$	$K^{\pm}\pi^{\mp}$	0.66	150 ± 20
$A_2^{\pm}(1310)\pi^{\pm}$	$K_S^0K^{\pm}$	0.0235	2800 ± 200
$K^{*\pm}(1420)K^{\mp}$	$K_S^0\pi^{\pm}$	0.15	90 ± 15
$K^{*0}(1420)K_S^0$	$K^{\pm}\pi^{\mp}$	0.30	120 ± 12
$S^*(980)\pi^0$	$K_S^0K_S^0$	0.25	46 ± 9
$f'(1515)\pi^0$	$K_S^0K_S^0$	0.25	24 ± 5
$K^{*\pm}(892)K^{*\mp}(892)$	$K_S^0\pi^{\pm}, K_S^0\pi^{\pm}$	0.33×0.33	570 ± 20
$K^{*0}(892)\bar{K}^{*0}(892)$	$K_S^0\pi^0, K^{\pm}\pi^{\mp}$	0.33×0.66	180 ± 25
$S^*(980)\rho^0$	$K_S^0K_S^0$	0.25	36 ± 10
$\varphi(1020)\rho^0$	$K_S^0K_L^0$	0.35	26 ± 10
$A_2^{\pm}(1310)\rho^{\mp}$	$K_S^0K^{\pm}$	0.0235	1430 ± 260
$D(1285)\pi^0$	$K_S^0K^{\pm}\pi^{\mp}$	0.33	20 ± 10
$E(1420)\pi^0$	$K_S^0K^{\pm}\pi^{\mp}$	0.33	40 ± 20
$D(1285)\rho^0$	$K_S^0K^{\pm}\pi^{\mp}$	0.33	20 ± 5

FIGURE CAPTIONS

- Fig. 1 Incident antiproton momentum distribution.
- Fig. 2 Cross section distribution for $\bar{p}p \rightarrow K_S^0 K_L^0$ and $\bar{p}p \rightarrow K_S^0 K_L^0$.
- Fig. 3 Production angular distributions for $\bar{p}p \rightarrow K_S^0 K_L^0$.
The solid curves correspond to the projection of the best fits using a Legendre polynomial expansion.
- Fig. 4 Behaviour of the Legendre polynomial expansion coefficients as a function of the beam momentum.
- Fig. 5 Dalitz plots for $\bar{p}p \rightarrow K_S^0 K^\pm \pi^\mp$:
(a) 702 MeV/c sample,
(b) 757 MeV/c sample.
- Fig. 6 $K^0 \pi^\mp$, $K^\pm \pi^\mp$ and $K_S^0 K^\pm$ effective mass distributions for $\bar{p}p \rightarrow K_S^0 K^\pm \pi^\mp$.
- Fig. 7 $K^{*\pm}(892)$, $K^{*0}(892)$ and $A_2^+(1310)$ production angular distributions for $\bar{p}p \rightarrow K_S^0 K^\pm \pi^\mp$.
- Fig. 8 Dalitz plot for $\bar{p}p \rightarrow K_S^0 K_S^0 \pi^0$.
- Fig. 9 (a) $K_S^0 K_S^0$ effective mass distribution for $\bar{p}p \rightarrow K_S^0 K_S^0 \pi^0$.
(b) $K_S^0 \pi^0$ effective mass distribution.
The solid curves correspond to the projection of the fit described in the text. The dotted lines show the S^* and non S^* contributions in the $K_S^0 K_S^0$ spectrum.
- Fig. 10 Missing mass distribution for the reaction $\bar{p}p \rightarrow K_S^0 + \text{neutrals}$.
- Figs 11-13 Two and three-body mass distributions for the $K_S^0 K_S^0 \pi^+ \pi^-$, $K_S^0 (K^0) \pi^+ \pi^-$ and $K_S^0 K^\pm \pi^\mp \pi^0$ final states. The solid curves correspond to the projection of the fit described in the text.

FIGURE CAPTIONS

- Fig. 14 $\bar{p}p \rightarrow K^* \bar{K}^*$ differential cross sections at 702 and 757 MeV/c.
- Fig. 15 $(K\bar{K}\pi)^\pm$ square effective mass distribution for the reaction $\bar{p}p \rightarrow K^0 \bar{K}^0 \pi^+ \pi^-$ at 702 and 757 MeV/c. Histograms (b) correspond to the sample with the double K^* production removed. Histograms (c) include the events with at least a $K\pi$ mass combination in the K^* mass region (0.84 - 0.94 GeV).
- Fig. 16 $K\bar{K}\pi$ squared effective mass distribution for $K_S^0(K^0)\pi^+\pi^-$ final state using the 702 MeV/c data.
- (a) Complete sample.
 - (b) The same sample but removing the events which passed the selection (e) described in the text.
 - (c-d) Sample (a) selecting and antiselecting the events with a track candidate to be ambiguous by ionization.
 - (e-f) Sample (c) selecting and antiselecting the events which are kinematically ambiguous between the $K_S^0 K^\mp \pi \pi^0$ and $\pi^+ \pi^- K_S^0(K^0)$ final states.
 - (g-h) Sample (e) but separating the two $K\bar{K}\pi$ mass combinations in the one (g) recoiling to, or the other (h) which includes, the ambiguous charged particles.

FIGURE CAPTIONS (Cont'd)

- Fig. 17 $K\bar{K}\pi$ mass distributions for a partial sample of 757 MeV/c events which have been declared ambiguous after identification at the scanning table.
- (a) $K\bar{K}\pi$ mass distribution for the $\pi^+\pi^-K_S^0(K^0)$ hypothesis.
 - (b) $K_S^0(K^0)\pi^\pm$ mass distribution for a sample of $K_S^0K^\pm\pi^\mp\pi^0$ Monte-Carlo generated events. The sample contains those events for which a misidentification of the K^+ gives a candidate to the $K_S^0\pi^+\pi^-(K^0)$ final state. The continuous line corresponds to the distribution which includes both $K_S^0(K^0)\pi^\pm$ mass combination. The dotted line corresponds to the distribution which includes only the $K_S^0(K^0)\pi^\pm$ combination recoiling to the artificially misidentified track.
 - (c-d) $K\bar{K}\pi$ combinations recoiling to, or including, respectively, the ambiguous track.
 - (e-f) $K\bar{K}\pi$ mass distributions for the sample (a) with χ^2 probability larger for the $K_S^0K^\pm\pi\pi^0$ or the $K_S^0(K^0)\pi^+\pi^-$ final states, respectively.
- Fig. 18 $K_S^0K^\pm\pi^\mp$ mass distribution for the $\bar{p}p \rightarrow K_S^0K^\pm\pi^\mp\pi^+\pi^-$ reactions. The D(1285) and E(1420) mesons are clearly observed. The solid curve corresponds to the projection of a fit in the D meson region [19].
- Fig. 19 $\pi^+\pi^-\pi^0$ mass distribution for the reaction $pp \rightarrow K_S^0K_S^0\pi^+\pi^-\pi^0$.
- Fig. 20 Effective mass distributions for the reaction $pp \rightarrow K_S^0K^\pm\pi^\mp\pi^+\pi^-\pi^0$.
- (a) $K_S^0K^\pm$,
 - (b) $\pi^+\pi^-\pi^0$.

FIGURE CAPTIONS (Cont'd)

Fig. 21 Missing mass spectrum for the reaction $\bar{p}p \rightarrow K_S^0 K_S^0 M$.

Fig. 22 Missing mass spectrum for the reaction $\bar{p}p \rightarrow K_S^0 K^\pm \pi^\mp M$.

Fig. 1

Fig. 2

$\cos \theta$

Fig. 3

Fig. 4

Fig. 5

Fig. 6

Fig. 7

Fig. 8

Fig. 9

Fig.10

Fig. 11

Fig.12

Fig.14

Fig.15

Fig.16

Fig.17

Fig.18

Fig.19

Fig.20

Fig.22

Fig.21