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New Experimental Results on $\bar{p}p \to K^0\bar{K}^0$ from 700 to 1100 MeV/c *

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Cross sections and angular data are presented for proton-antiproton annihilation into K_SK_L and K_SK_S at six laboratory momenta from 686 to 1098 MeV/c. Unlike results reported elsewhere, the rates for $C=-1$ and $C=+1$ states are found to be comparable within statistics. Also, evidence is presented that at least several waves contribute to the direct-channel amplitude with different isospin as well as angular momentum quantum numbers.

Recently, Benvenuti *et al.*[1] reported that in the final state $\bar{p}p \to K^0\bar{K}^0$ they found only one event of the type

$$\bar{p}p \to K_SK_S\,, \tag{1}$$

while in the same film they found 71 events of the type

$$\bar{p}p \to K_S(K^0)\,, \tag{2}$$

where K_S represents a visible $K_S^0 \to \pi^+\pi^-$ and (K^0) represents an unobserved K^0 meson. They found an enhancement in reaction (2) at a beam momentum of about 600 MeV/c. (Most of their data were in the 400–800-MeV/c range.) Based on the near absence of reaction (1) they concluded that this effect must have $C=-1$. From their angular analysis they also concluded that this effect probably has $J=1$, and proposed the name $\rho(1970)$ for this state.[2]

Our experiment (performed in the same beam and hydrogen bubble chamber) covers $\bar{p}$ initial momentum from 700 to 1100 MeV/c, thus overlapping about 20% of the data of Benvenuti *et al.* Since our data do not extend down to 600 MeV/c, we cannot comment on the existence of their enhancement. However, we observe a significant rate for reaction (1). In fact, we find the cross sections for reactions (1) and (2) roughly equal over our entire energy range. As regards the region of overlap, this result is in disagreement with the observation of Benvenuti *et al.*, and we believe that it may cast some doubt on their assertion that their effect must be pure $C=-1$.

Our data were taken from 220 000 photographs of antiproton interactions in the BNL 30-inch hydrogen bubble chamber. The chamber was exposed to the AGS antiproton beam at the six mean lab momenta of 686, 772, 861, 943, 1037, and 1098 MeV/c.

The film was scanned and measured twice for events having one or more V's pointing back to a zero-pronged vertex. Approximately 575 events were found and measured. The combined scanning efficiency was $(82\pm3)\%$, with no significant variation with beam momentum.

The events were processed by the programs TVGP-SQUAW . Eight events were observed to fit $\bar{p}p \to K_SK_S$, with confidence levels greater than 1% for a ten-constraint fit. Thirty-five events were observed to fit $\bar{p}p \to K_S(K^0)$, with confidence levels greater than 1% for a four-constraint fit. The eight events which fit K_SK_S also were tested with the seven-constraint hypothesis $K_SK_S\pi^0$, and all fits gave confidence levels less than 0.1%. The confidence levels for the eight K_SK_S fits were 1.4%, 2.3%, 4.5%, 5.6%, 20.1%, 53.6%, 78.5%, and 84.1%.

As a check on the above event assignments we plot the missing mass squared as calculated in SQUAW for the hypothesis

$$\bar{p}p \to K^0 + \text{missing mass} . \qquad (3)$$

Figure 1(a) shows all of our single-V events. A clear signal is seen at the K^0 mass [as well as at the $K^*(890)$ mass]. From this plot we estimate a contamination of less than two events in our sample of 35 events fitting reaction (2).

For our double-V events we have computed the invariant mass recoiling against each of the two visible K^0's. Figure 1(b) is a scatter plot of the squares of these invariant masses. A clear signal is seen in the region where the K^0 bands cross. From this plot we estimate that at most only one of our eight events of type (1) is due to contamination from processes such as $K^0\bar{K}^0\pi^0$.

In calculating cross sections and angular distributions all events were weighted to correct for the probability that a K_S escapes the bubble chamber and the probability that a K_S decays so close to the production vertex that the π^+ and π^- are mistaken for the tracks from a two-pronged event. The average weight of 1.1 was used to compute the cross sections. The individual weights were used in the angular distribution analysis below. The data were also corrected for K_S neutral decays.

In Fig. 2(a) we display the cross section for $\bar{p}p \to K_SK_S$ as a function of incident beam momentum. A least-squares fit gives

$$\sigma = (7.0 \pm 3.8)P_L^{-1.7\pm2.3}\ \mu\text{b} .$$

Here P_L is the lab momentum of the $\bar{p}$ in GeV/c. Our data do not determine the energy dependence very well and we note that, although the cross section is consistent with no energy variation, it is consistent in both magnitude and shape with the K_LK_S data discussed below. The data are consistent with the point of Barlow *et al.*[3] at 1200 MeV/c, and with that of Lörstad *et al.*[4] at 700 MeV/c, but in disagreement with the statement of Benvenuti *et al.*[1] that the cross section is essentially zero up to 800 MeV/c. If their one event were in our energy range, it would correspond to a cross section of less than 2 μb,[5] which is to be compared with our first two data points representing three events and cross sections of 18 ± 13 and 6 ± 6 μb, respectively.

In Fig. 2(b) we show the cross section for $\bar{p}p \to K_SK_L$. A least-squares fit gives

$$\sigma = (11.0 \pm 4.0)P_L^{(-3.25\pm1.44)}\ \mu\text{b} .$$

This cross section is clearly falling with momentum with a slope consistent with baryon exchange; here Σ trajectories would contribute to the crossed-channel amplitude. Our data are consistent with Ref. 1 and Ref. 4 at ~700 MeV/c but in disagreement with the point of Ref. 3 at 1200 MeV/c.

Our data indicate that annihilation into $K^0\bar{K}^0$ is taking place from both $C=+$ and $C=-$ states of the $\bar{p}p$ system and in neither case is the annihilation obviously resonant. The consistency between the two processes suggests a crossed-channel

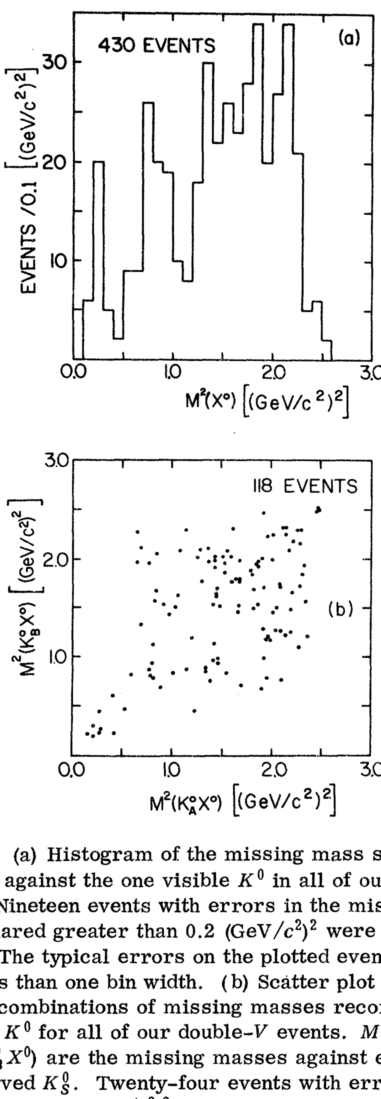

FIG. 1. (a) Histogram of the missing mass squared recoiling against the one visible K^0 in all of our single-V events. Nineteen events with errors in the missing mass squared greater than 0.2 (GeV/c^2)^2 were not plotted. The typical errors on the plotted events are much less than one bin width. (b) Scatter plot of the two possible combinations of missing masses recoiling against a K^0 for all of our double-V events. $M(K_A^0X^0)$ and $M(K_B^0X^0)$ are the missing masses against each of the observed K_S^0. Twenty-four events with errors greater than 0.1 (GeV/c^2)^2 were not plotted. Typical errors are about equal to the diameters of the dots.

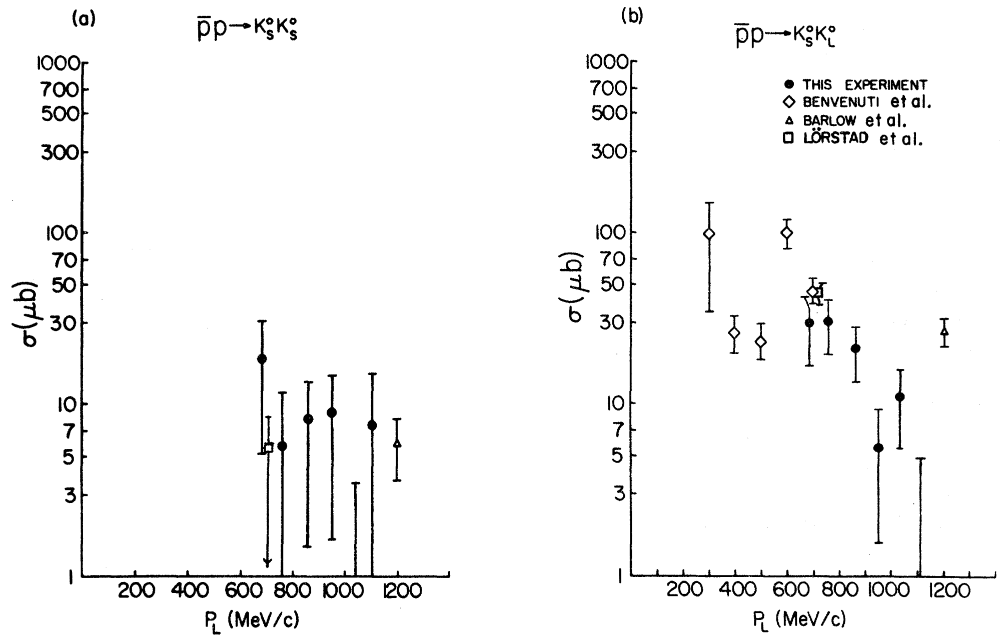

FIG. 2. (a) Cross sections for the reaction $\bar{p}p \rightarrow K_S K_S$ as a function of beam momentum. (b) Cross sections for the reaction $\bar{p}p \rightarrow K_S K_L$ as a function of beam momentum.

dynamical mechanism, since the crossing relations provide amplitudes for all $\bar{p}p$ initial waves.

We next compare the data with our previously published[6] $\bar{p}p \rightarrow K^+K^-$ data where the cross section is fitted by

$$\sigma = (103 \pm 15) P_L^{-(0.59 \pm 0.77)} \ \mu\text{b} .$$

The K^+K^- cross section is larger than that for $K^0\bar{K}^0$ and less rapidly falling. This may be readily explained in a crossed-channel picture where for $\bar{p}p \rightarrow K^+K^-$ we have Λ as well as Σ exchange. From the direct-channel point of view the amplitudes for each of the $\bar{p}p$ initial waves into K^+K^- are related to those into $K_S K_S$ (J even) and into $K_S K_L$ (J odd) via isotopic spin. If either isotopic spin 0 or 1 dominated, we would obtain the cross-section equality

$$\sigma_{K^+K^-} = \sigma_{K_S K_L} + 2\sigma_{K_S K_S} .$$

This relation is clearly not satisfied by our data, indicating that at least several waves contribute to the direct-channel amplitude with different I as well as J quantum numbers.

Angular Distribution

Since we have eight events of the type $\bar{p}p \rightarrow K_S K_S$, we must consider the angular distribution summed over our energies. Expanding the normalized distributions in Legendre polynomials

$$f(\theta) = \sum_{l=\text{even}} A_l P_l(\cos\theta) \quad (A_0 = 0.5) \tag{4}$$

we find that coefficients with $l \geqslant 6$ are consistent

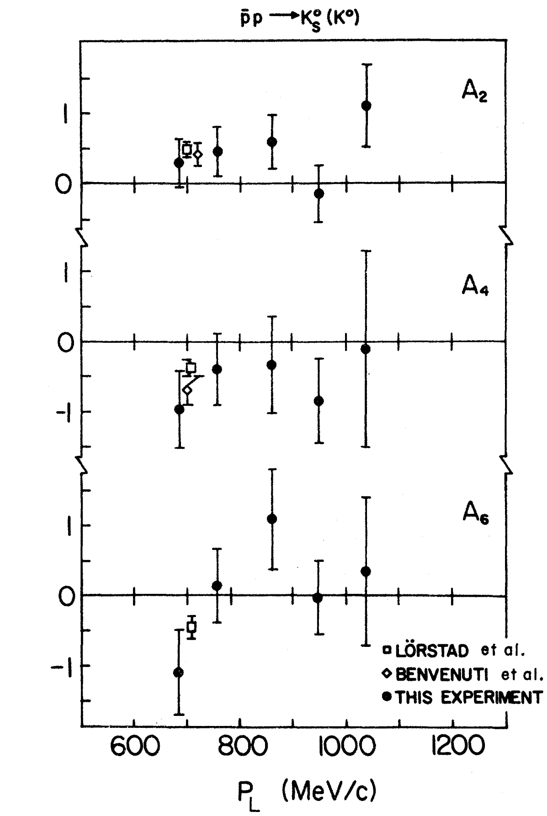

FIG. 3. The Legendre coefficients A_2, A_4, and A_6 for the reaction $\bar{p}p \rightarrow K_S(K^0)$ as a function of beam momentum. The coefficients are normalized such that $A_0 = 0.5$.

with zero. By taking moments of the Legendre polynomials we compute $A_2 = 0.29 \pm 0.30$ and $A_4 = -0.98 \pm 0.45$. It is shown below that these coefficients are consistent with our results for $\bar{p}p \to K_S(K^0)$.

Now turning to the $\bar{p}p \to K_S(K^0)$, we note that C invariance implies that the K_SK_L data are symmetrical about 90° in the center-of-mass system. The observed forward-backward asymmetry in this experiment for $K_S(K^0)$ events of all energies is $(F-B)/(F+B) = 0.03 \pm 0.17$. The data for each of our six energies are also consistent with symmetry. We compute the coefficients of expansion (4) and display the results in Fig. 3. The coefficients A_l are consistent with the results of Ref. 1 and Ref. 4 and with our average coefficients for $\bar{p}p \to K_SK_S$. We expect 8 ± 3 events of the $K_S(K^0)$ sample to be K_SK_S where one of the K_S has decayed neutrally; the latter result indicates no significant distortion of the K_SK_L angular coefficients due to this contamination.

We next compare these A_l's with those we reported[6] for $\bar{p}p \to K^+K^-$. In those data we found a rapid variation in the angular distribution and an enhancement in the channel cross section between 800 and 1000 MeV/c. The results were found to be in agreement with the K^+K^- data of Nicholson *et al.*[7] which yielded the even Legendre coefficients in this energy region.

The angular coefficients for K_SK_L bear no obvious resemblance to those for K^+K^-. The difference in the cross sections is not surprising in view of our result that waves of several J's and I's annihilate into $K\bar{K}$. The angular distribution for K_SK_L is due to waves of odd J only and cannot be expected to look like that for K^+K^- which has both even and odd J and whose amplitudes are further a different linear combination of $I=0$ and $I=1$.

The angular coefficients for $\bar{p}p \to K_SK_L$ are not rapidly varying with energy; in fact, within our quite meager statistics they are consistent with no energy dependence and we cannot distinguish among hypotheses for the $\bar{p}p$ annihilation mechanism. The systematically positive value for A_2 is suggestive, in agreement with Ref. 1 and Ref. 4, of a $^3D_1$ initial state for this process.

Conclusions

We show that annihilation of $\bar{p}p$ into $K^0\bar{K}^0$ proceeds via states of both positive and negative C and both $I=0$ and $I=1$. We observe no resonance production. Since there is no $\bar{p}p \to K_SK_S$ annihilation in S state, and centrifugal barriers suppress large orbital angular momenta, it is likely that the ^3P states are important for the K_SK_S reaction at our energies. Our results are not consistent with those of Ref. 1 which finds no rate for $\bar{p}p \to K_SK_S$ below 800 MeV/c.

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