Experimental Study of $\bar{p}p \rightarrow K_S^0 K_L^0$ in the
Momentum Range 300 - 750 Mev/c^{*}

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Several studies of low-energy $\bar{p}p$ interactions involving the possible existence of vector-meson states in the 1900-2000 MeV mass region have recently appeared in the literature.¹⁻⁴ In particular the annihilation channel

$$\bar{p}p \rightarrow K_S^0 + K_L^0, \quad (1)$$

where the final state is a pure $C=-1$ state, might be useful in searching for high-mass vector mesons. We present a study of reaction (1) where we obtain results which disagree somewhat with the cross section, but are reasonably consistent with the angular distributions presented in earlier studies.^{2,3} We do not see any clear evidence for a resonant ("S meson") state.

Our data were obtained from a 245,000-picture exposure of the Brookhaven

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National Laboratory 30" hydrogen bubble chamber to a separated antiproton beam whose momentum was varied over the range 350-750 MeV/c in eight settings. The entire film has been scanned for all events with one or two vees associated with a beam track ending in the chamber. These events represent the following:

$$\bar{p}p \rightarrow K_S^0 + (K^0) + n(\pi^0) \quad (2)$$

$$\bar{p}p \rightarrow K_S^0 + K_S^0 + n(\pi^0) \quad (3)$$

In Fig. 1(a) we display a histogram of the square of the missing mass in reaction (2); this contains 600 events. Fig. 1(b) is a plot of the square of the mass recoiling against one of the K^0 's in reaction (3). Each of the 142 events contributes two combinations to the plot, with a weight of 0.5 assigned to each combination. Subtracting the spectrum of Fig. 1(b) from that of Fig. 1(a) yields a spectrum of pure

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

The subtraction is shown as the hatched area in Fig. 1(a). A peak near 0.25 GeV^2 with width $\Gamma \sim 0.16 \text{ GeV}^2$ is identified as K_L^0 . A K^{*0} peak is also seen near 0.8 GeV^2 , although there is considerable background; this contrasts with the apparent lack of a K^{*0} signal in reaction (3). We also note only one event fitting

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

in agreement with an earlier experiment over the same momentum range.²

We now restrict ourselves to a study of

$$\bar{p}p \rightarrow K_S^0 + K_L^0 \quad (6)$$

by imposing the mass selection of $0.08 < MM^2 < 0.40 \text{ GeV}^2$ for the K_L^0 in reaction (4). In this interval there were 76 candidates which had a good χ^2 for the kine-

matic fit to reaction (6). After imposition of the usual fiducial-volume and minimum- K_S^0 -length criteria, 69 events remained. (The sample of Ref. 2 contained 71 events.) Fig. 2(a) shows how these weighted events were distributed over the antiproton momentum range. Solid lines display the results, while dotted lines show the effect of shifted binning.⁵ In order to determine the total track length, we measured a random sample of 26,000 4-prong events distributed over the entire momentum range and subjected to the same fiducial volume criteria as used for reaction (6). From a determination of the antiproton momentum at interaction, the known 4-prong total cross sections,⁶ and the total number of 4-prong events in our experiment, we obtained the total antiproton track-length as a function of momentum. The results are given in Fig. 2(b). The arrows indicate nominal values for each of our eight momentum settings.

The scanning efficiency (85%) and the correction for $K_S^0 \rightarrow$ neutrals are combined with the preceding results to obtain the cross section for reaction (6) as a function of antiproton laboratory momentum. As displayed in Fig. 2(c), we find the cross section to be essentially flat from 300 - 750 MeV/c. The comparable cross section plot from the Univ. of Wisconsin² is given in Fig. 2(d). This plot suggests a peak near 600 MeV/c ($E^* \sim 1970$ MeV) which is not supported by our data. We find no momentum-dependent biases in our film or our analysis procedures, and the normalization to 4-prong cross section in this momentum range excludes any pion beam contamination.

The angular distributions for our data are given in Fig. 3, where we define θ^* as the angle between the K_S^0 and the incident antiproton in the $\bar{p}p$ c.m. We span the momentum range in two sets of bins [Fig. 3(a) and 3(b)] to show the effects of binning with our low statistics. Events which failed our fiducial volume cuts are also shown. Except for the lowest momentum bin, which suffers from poor statistics, there is evidence of a strong $\cos^2 \theta^*$ dependence. Indeed,

we fitted our data by a Legendre polynomial expansion

$$\frac{d\sigma}{d\Omega} = \sum_n A_n P_n(\cos \theta^*) \quad (7)$$

allowing both even and odd A_n . Results of the analysis are presented as ratios of the A_n coefficients in Fig. 4. The expected value of A_2/A_0 is 1.0 for a pure 3D_1 transition; this is shown as the dotted line in the plot of our data in Fig. 4(a) and of the Wisconsin data in Fig. 4(b). Our data are consistent with the interpretation of the initial $\bar{p}p$ state as a 3D_1 across the entire momentum range. We do not see any peaking of A_2/A_0 in the 500-600 MeV/c region. The ratios A_4/A_0 for our data and for the Wisconsin data are given in Fig. 4(c) and 4(d), respectively. Our data are consistent with $A_4/A_0 = 0$ over the entire momentum range. Finally, as a check, we present the ratios of the odd coefficients A_1/A_0 in Fig. 4(e) and A_3/A_0 in Fig. 4(f); these should be zero for $K_S^0 K_L^0$ production. Except for the first momentum bin, which suffers from poorest statistics, these ratios are consistent with zero over the momentum range. (The A_1 and A_3 determinations are especially strongly correlated at the lowest momentum because of the paucity of data.) Higher coefficients (like A_6) were found to be small; we generally agree with the statement of Ref. 2 that $A_2 > A_4$ and $A_2 > A_6$ over our momentum range. This fact indicates an absence of higher angular momentum $\bar{p}p$ initial states such as 3D_3 and 3G_3 .

In an attempt to learn more (e.g., I-spin) from channels other than $\bar{p}p \rightarrow K_S^0 K_L^0$, we have also studied $\bar{p}p \rightarrow \pi^+ \pi^- \pi^0$. Preliminary results show little evidence of a $\rho\pi$ final state and no significant dependence on incident momentum.

In conclusion, we find our data in agreement with the interpretation of the initial $\bar{p}p$ state as 3D_1 , but find no evidence in the cross section near $p_{lab} \approx 600$ MeV/c to support a possible $J^{PC} = 1^{--}$ meson corresponding to a mass of 1970 MeV.²

References

1. D. Cline et al., Phys. Rev. Letters 21, 1268 (1968).
2. A. Benvenuti et al., Phys. Rev. Letters 27, 283 (1971).
3. D. Cline and R. Rutz, Phys. Rev. D5, 778 (1972).
4. D. Cline, in talk given at Argonne National Laboratory Summer Workshop (1971).
See ANL/HEP-7208 Vol. II, 620.
5. We present the differently binned results on the same plot primarily because we wish to compare with the results of Ref. 2, where double binning is used.
6. Compilation of Cross Sections in Antiproton Induced Reactions, CERN/HERA 70-3 (1970).

Figures

1. (a) Square of the missing mass for $\bar{p}p \rightarrow K_S^0 + (MM)$, 600 events (14 of which are off-scale). Hatched events are those subtracted as discussed in text.
- (b) Square of mass recoiling against one of the K_S^0 ; 142 total events, two combinations per event (weighted by 0.5 each).
2. (a) Weighted events satisfying $\bar{p}p \rightarrow K_S^0 + K_L^0$ as a function of lab momentum. Overlapping bins are used.
- (b) Antiproton path-length as a function of lab momentum; arrows denote nominal values of beam momentum settings.
- (c) Total cross section for $\bar{p}p \rightarrow K_S^0 K_L^0$ (this experiment).
- (d) Total cross section for $\bar{p}p \rightarrow K_S^0 K_L^0$ (Wisconsin).
3. (a),(b) Angular distribution of K_S^0 over two binnings of the momentum range, with $\cos \theta^* \equiv \hat{K}_S^0 \cdot \hat{p}$.
4. Ratios of A_n coefficients
 - (a) A_2/A_0 , this experiment.
 - (b) A_2/A_0 , Wisconsin.²
 - (c) A_4/A_0 , this experiment.
 - (d) A_4/A_0 , Wisconsin.²
 - (e) A_1/A_0 , this experiment.
 - (f) A_3/A_0 , this experiment.

Figure 1

FIGURE 2

/// FIDUCIAL VOLUME FAILURE

$\cos \theta^*$

FIGURE 3

FIGURE 4