since the produced hadrons are to be detected simultaneously, no serious background problem arises from Bhabha scattering and its radiative corrections. The background due to hadrons produced in $C = -$ states by the bremsstrahlung of virtual photons in e^+e^- collisions appears to be strongly suppressed in the deep inelastic region.

[9]R. B. Curtis, Phys. Rev. 104, 211 (1956).

[10]R. H. Dalitz and D. R. Yennie, Phys. Rev. 105, 1598 (1957).

[11]If the electron 2 is detected at the angle between θ_{min} ($\gg m_e/E$) and θ_{max}, $N(E_\gamma, \theta_{max})$ in (5) should be replaced by $N(E_\gamma, \theta_{max}) - N(E_\gamma, \theta_{min})$.

[12]E. D. Bloom *et al.*, Phys. Rev. Lett. 23, 930 (1969).

[13]C. G. Callan, Jr., and D. J. Gross, Phys. Rev. Lett. 22, 156 (1969).

Experimental Evidence for a High-Mass Vector Meson*

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We have measured the cross section for the reaction $\bar{p}p \to K_S^0K_L^0$ from 100–800 MeV/c. A significant enhancement in the cross section is observed at a mean momentum of 600 MeV/c. A Legendre-polynomial analysis of the angular distributions also shows an enhancement in the A_2 coefficient in the same momentum range. A plausible explanation of the data indicates a new meson state $\rho(1970)$ with a mass $M = 1968$ MeV, width $\Gamma = 35$ MeV, and $J^{PC} = 1^{--}$.

Recently many theories and phenomenological analyses have suggested the existence of additional vector-meson states.[1,2] However, no conclusive evidence for such states has been obtained from any production experiment to date.[3] Presumably if these states were formed in production experiments they would be masked by high-spin states. In contrast, formation experiments with the $\bar{p}p$ system might be sensitive to the existence of low-spin states since high-spin states should be relatively suppressed by the centrifigal barrier at low antiproton momentum. In addition the selection of particular annihilation final states can enhance the signal to noise for selected mesonic quantum members. Annihilation states with $K^0\bar{K}^0$ pairs are particularly useful for isolating selected charge-conjugation states of the $\bar{p}p$ system. In particular the $K_L^0K_S^0$ final state is a pure $C = -1$ state as are vector mesons. In this note we report a study of the cross section and angular distribution for the annihilation process in the $K_L^0K_S^0$ final state below 800 MeV/c antiproton momentum. We present evidence for the existence of a new high-mass vector meson.

The data reported in this note were obtained from a 250 000 picture exposure of the Brookhaven National Laboratory 30-in. bubble chamber to a separated antiproton beam at the alternating-gradient synchrotron. The beam momentum was varied so that the momentum range of 800–400 MeV/c was covered with approximate uniform flux. The momentum range of 100–400 MeV/c was covered with a considerably smaller flux. The primary purpose of the exposure was to search for s-channel structure in low-energy $\bar{p}p$ scattering and several reports on this subject have already appeared.[4-6] Each picture contained approximately ten antiprotons giving a total of 2.5×10^6 antiprotons in the exposure.

The film has been scanned for all events with one or two pointing V's and a zero-prong star. These events fall into the categories

$$\bar{p}p \to K_S^0 + K_S^0 + n(\pi^0), \tag{1}$$

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

where $(K^0)_m$ represents either a K_L^0 meson which leaves the bubble chamber or a K_S^0 with a neutral decay and K_S^0 represents a visible $\pi^+\pi^-$, K_S^0 decay. All events of type 1 were tested for the hypothesis

$$\bar{p}p \to K_S^0 + K_S^0, \tag{3}$$

and only one event in this category was observed in the entire experiment. The significance of the low rate for this process is discussed in another place.[7] For Reaction (2) a missing-mass spectrum recoiling against the K_S^0 was constructed and showed a very clean bump at the position of the K^0 mass. The mass squared and half-width of the bump were

$$M^2 = 0.250\ \mathrm{GeV}^2, \quad \Gamma/2 = 0.08\ \mathrm{GeV}^2;$$

71 events were selected by a mass cut centered on M_k and by a physicist's examination of the event. We expect less than one background event in this sample.

Because of the low rate for process (3) the bulk of these events must be attributed to the process

$$\bar{p}p \rightarrow K_S^0 + K_L^0 \tag{4}$$

with less than one event being misidentified as Reaction (3) with a K_S^0 that decays neutrally. One half of the film was rescanned and the scanning efficiency was found to be essentially independent of beam momentum above 500 MeV/c. The scanning, measuring, and program efficiencies have been taken into account in the present analysis.

In order to obtain the reaction cross section a careful measurement of the antiproton path length as a function of beam momentum was made. 17 000 beam tracks were measured for this analysis. The same fiducial volume was used for both event selection and flux measurement. The path-length distribution was found to be in agreement with an earlier determination.[5] As a further check on the flux determination the cross section for the process

$$\bar{p}p \rightarrow K_S^0 + K^*(890) \tag{5}$$

was computed. The $K^*(890)$ was selected from events of type 2 within the missing mass of 890 ± 50 MeV. The cross section for this reaction is shown in Fig. 1(a). The $K^*(890)$ production in Reaction (1) was found to be negligible. The cross section appears to fall rapidly (faster than $1/v$) to a momentum of 300–500 MeV/c and then to level off with no apparent structure in the cross section above 500 MeV/c. A similar rapid fall off at low momentum and a break in the cross section at 300–400 MeV/c has been observed in a total annihilation cross-section measurement and may be characteristic of many $\bar{p}p$ annihilation channels.[6] In Fig. 1(b) we present the cross section for Reaction (4). The data have been plotted in overlapping momentum bins to show better the effects of binning for low-statistics data. A significant enhancement of the cross section appears in the vicinity of 600 MeV/c. For comparison we show the cross section for Reaction (4) at 700 and 1200 MeV/c determined by two other groups.[8,9] The agreement between our measurements and the measurement of Lörstad *et al.* at 700 MeV/c is excellent.[8] A comparison between the smooth behavior of the $K_S^0K^*(890)$ cross section and the $K_S^0K_L^0$ cross section as shown in Figs. 1(a) and 1(b), respectively, indicates that the structure in $K_S^0K_L^0$ does not come from the flux determination. An estimate of the mass and width of the enhancement was made by comparing the data with a calculation of the cross section which was based on the incoherent addition of a background and Breit-Wigner resonant amplitude.[10] The resulting curve is also shown in Fig. 1(b) with

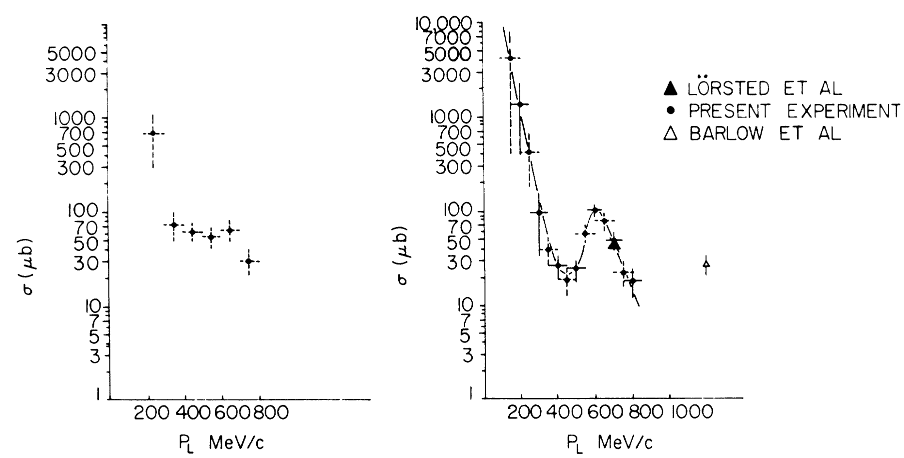

FIG. 1. Cross section for the reaction $\bar{p}p \rightarrow K_S^0K^*(890)$ as a function of antiproton momentum. The $K^*(890)$ was selected from the mass band 890 ± 50 MeV. (b) Cross section for $\bar{p}p \rightarrow K_S^0K_L^0$ as a function of antiproton momentum. The cross section has been plotted in overlapping bins to show the effects of different binning of the data. Also shown are the cross sections for this reaction at 700 and 1200 MeV/c obtained from Refs. 7 and 8. The solid curves in this figure represent a fit to the data with background plus Breit-Wigner–resonance form as explained in the text.

mass $M \cong 1968$ MeV and width $\Gamma \cong 35$ MeV. We consider the existence of this enhancement to be indicative of a new $C = -1$ state.

We have fitted our data and the data of Lörstad by a Legendre-polynomial expansion,

$$d\sigma/d\Omega = \sum A_n P_n(\cos\theta); \tag{7}$$

A_0 is simply related to the total cross section shown in Fig. 1(b). The angular distribution was folded around 90° because only the even n coefficients can be different from 0 for the $K^0\bar{K}^0$ final state. A check on possible biases in the data was made by fitting the unfolded data to expression (7) allowing even and odd A_n's. The A_n values for odd n were found to be small and consistent with zero. We cannot prove that the higher coefficients are zero, but the A_2 coefficient is definitely larger than the A_4 and A_6 coefficients below 700 MeV/c.[11] This conclusion is confirmed with better statistics by the data of Lörstad *et al.* at 700 MeV/c. In fact these authors have suggested that Reaction (4) is dominated by the $^3D_1$ initial $\bar{p}p$ state leading to a $J^{PC} = 1^{--}$ final state.[8,12] Our study supports this conclusion in the vicinity of the 600 MeV/c enhancement. Figures 2(a) and 2(b) show the ratios of Legendre coefficients A_2/A_0 and A_4/A_0, respectively, for this experiment and the experiment of Lörstad *et al.*[8] A striking peak in the A_2/A_0 ratio is observed in the vicinity of 500–600 MeV/c. The A_2/A_0 ratio expected for a pure $^3D_1$ transition is 1 and the peak value of A_2/A_0 reaches ~2 indicating some interference with the $^3S_1$ initial state. A pure $^3S_1$ state would give $A_2/A_0 = 0$.

The quantum numbers available for the enhancement at 600 MeV/c are 1^{--} ($^3S_1$ or $^3D_1$), or 3^{--} ($^3D_3$ or $^3G_3$). In the second case it would be expected that large values of A_4/A_0 and A_6/A_0 would be observed and that these ratios should show structure in the vicinity of the enhancement. Since neither the present experiment nor the experiment of Lörstad *et al.* shows evidence for large A_6/A_0 or A_4/A_0,[8,11,12] we conclude that the striking structure in A_2/A_0 is suggestive of the quantum numbers 1^{--} for the 1970-MeV enhancement. Of course much higher statistics would be required to furnish conclusive proof.

We also note that the reaction

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

shows an abrupt change in the angular distribution in the vicinity of 600 MeV/c,[13] which is perhaps related to the structure reported here. Although structure has been observed in the backward hemisphere $\bar{p}p$ elastic scattering,[4,5] this structure appears to occur at a slightly lower mass than the structure observed here. We note also that some data exist for the $\bar{p}p \rightarrow K^+K^-$ channel.[14]

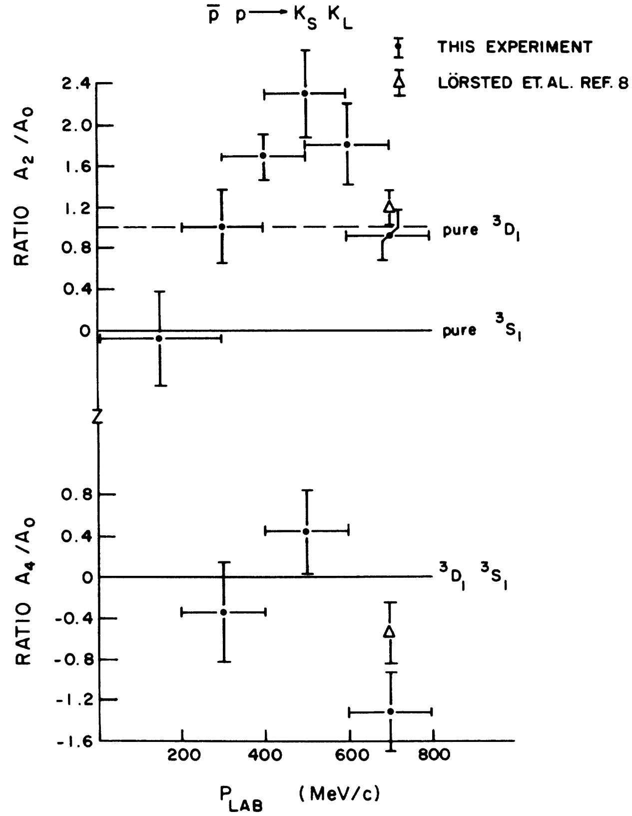

FIG. 2. (a) The ratio of the coefficients A_2/A_0 from a fit to the $\bar{p}p \rightarrow K_S{}^0K_L{}^0$ angular distribution by a Legendre-polynomial expansion. Also shown are the results of a fit to the data of Lörstad *et al.* The horizontal lines denote the value of this ratio expected for either a pure $^3S_1$ or $^3D_1$ initial state. In some cases the data are plotted in overlapping bins. (b) The ratio A_4/A_0 from a Legendre-polynomial fit to the $\bar{p}p \rightarrow K_S{}^0K_L{}^0$ angular distribution from this experiment and the experiment of Lörstad *et al.* The horizontal line shows the expectations for this ratio of a pure $^3S_1$ or $^3D_1$ initial state.

We note that the state observed here has the correct mass to be a member of the "s" tower or equivalently the third daughter of the (ρ,ω) trajectory.[1]

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[1]These states have been variously called ρ' or ω' states. See, for example, G. Veneziano, Nuovo Cimento 57A, 190 (1968); V. Barger and D. Cline, Phys. Rev.

182, 1849 (1969).

[2]Some evidence for secondary trajectories have been obtained from fitting various high-energy cross section. See, for example, V. Barger and R. J. N. Phillips, Phys. Rev. Lett. 21, 865 (1968); D. Cline, J. Matos, and D. D. Reeder, Phys. Rev. Lett. 23, 1318 (1969).

[3]G. McClellan *et al.*, Phys. Rev. Lett. 23, 718 (1969); H. Alvensleben *et al.*, Phys. Rev. Lett. 26, 273 (1971); F. Bulos *et al.*, Phys. Rev. Lett. 26, 149 (1971); B. Oh *et al.*, Phys. Rev. D 1, 2494 (1970).

[4]D. Cline *et al.*, Phys. Rev. Lett. 21, 1268 (1968).

[5]D. Cline, J. English, and D. D. Reeder, "Evidence for a Narrow, High Spin Boson State with Mass 1925 MeV" (to be published).

[6]D. Cline, J. English, and D. D. Reeder, Phys. Rev. Lett. 27, 71 (1971).

[7]A. Benvenuti, D. Cline, D. D. Reeder, and R. Rutz, to be published.

[8]B. Lörstad, Ch. D'Andlau, A. Aster, J. Cohen-Genouna, M. Della Negra, M. Aguilar-Benitez, J. Barlow, L. D. Jacobs, P. Malechi, and L. Montanet, in Proceedings of the Fifth International Conference on Elementary Particles, Lund, Sweden, 25 June-1 July 1969 (to be published). We wish to thank Dr. Montanet from CERN for sending us a copy of this report.

[9]J. Barlow *et al.*, Nuovo Cimento 50, 701 (1967).

[10]The parametrization that was found to fit the data best was $\sigma = C_1 \exp(-C_2 p) + C_3\{\Gamma/[(E-M)^2 + \Gamma^2/4]\}$, where M and Γ are the mass and width of the enhancement, respectively, and are solved along with the unknown constants C_1, C_2, and C_3. The center of mass energy of the $\bar{p}p$ system is E, and the momentum of the antiproton in the center of mass is p. The curve shown drawn through the points of Fig. 1(b) is very nearly the same curve for both binnings of the data.

[11]All fits to our data gave values of A_6/A_0 that were consistent with zero.

[12]If the $^3D_3$ initial state were to dominate, the resulting angular distribution would have $\cos^4\theta$ terms. In this case $A_4/A_0 = 0.84$ and $A_2/A_0 = 1.14$, which is inconsistent with the magnitude and sign of A_4/A_0 shown in Fig. 2(b).

[13]We have compiled the available data on the reaction $\bar{p}p \rightarrow \pi^+\pi^-$ below 800-MeV/c antiproton momentum and have made a Legendre-polynomial fit to the data. The A_1 and A_4 coefficients appear to go through zero in the vicinity of 600 MeV/c. The results of this analysis and references to the experimental data are reported in Ref. 6.

[14]Nicholson *et al.*, Phys. Rev. Lett. 23, 603 (1969). This experiment studied K^+K^- production which includes both $C = +1$ and $C = -1$ states. Therefore there is no simple connection between their results and the present experiment where the $C = -1$ channel is studied.