e.g., the fragmentation region of particle B.

Relation (4a) is simplified if both B and C have isospin zero, by analogy with Eq. (1). For example,

$$f(\bar{p}d\to\omega)-f(pd\to\omega)=3[f(K^-d\to\omega)-f(K^+d\to\omega)], \tag{5a}$$

$$f(\bar{p}d\to\eta)-f(pd\to\eta)=3[f(K^-d\to\eta)-f(K^+d\to\eta)]. \tag{5b}$$

It would be interesting to see whether the agreement with experiment for relations (4) and (5) is comparable to that for relations (1) and (2).

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[4]A very striking example of the breakdown of these regularities is the change in behavior of $\sigma_{tot}(K^+p)$ and $\sigma_{tot}(pp)$. Below 20 GeV/c, $\sigma_{tot}(K^+p)$ is constant and $\sigma_{tot}(pp)$ is slowly decreasing. Above 20 GeV/c, $\sigma_{tot}(pp)$ becomes constant and $\sigma_{tot}(K^+p)$ increases. The difference between the two regions is clearly exhibited on a plot of $\sigma_{tot}(K^+p)$ vs $\sigma_{tot}(pp)$, as suggested by H. J. Lipkin and V. Rabl, Nucl. Phys. B27, 464 (1971). A curve through the data changes abruptly from a horizontal line $\sigma_{tot}(K^+p)$ = const to a vertical line $\sigma_{tot}(pp)$ = const.

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PHYSICAL REVIEW D VOLUME 5, NUMBER 3 1 FEBRUARY 1972

Direct-Channel Interference in $\bar{N}N\to K\bar{K}$ at Low Energy and Meson Towers*

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The strong suppression of the cross section for the low-energy reaction $\bar{p}p\to K_S^0K_S^0$ as compared to $\bar{p}p\to K_S^0K_L^0$ and $\bar{p}p\to K^+K^-$ is explained as being due to the direct-channel excitation of two massive $C=+1$ boson resonances with $I=1$ and $I=0$, respectively. It is thus suggested that two $J^P=2^+$ states with masses below 2.0 GeV and with approximately equal couplings to the $\bar{N}N$ and $K\bar{K}$ systems, and produced in phase, provide a "natural" explanation of the data. Above 1.2 GeV/c the interference effects appear to disappear and possibly a new physical mechanism for $K\bar{K}$ production is observed.

Some time ago Lipkin suggested that the $\bar{K}K$ decay modes of high-mass bosons might show striking interference effects when particular charge states of the $K\bar{K}$ system were observed.[1] In particular, when two nearly mass-degenerate states with different isospin, as for example the f^0-A_2 mesons, *both* decay into the $K\bar{K}$ system, and provided they are produced in phase, interference may result.[2] Unfortunately, in the case of the f^0-A_2 system the present experimental data have not indicated evidence for or against this interference.[3-5] Furthermore, since the f^0 and A_2 are likely produced by different exchange mechanisms, it is probable that they will not be produced in phase, and the resulting interference effects may be small.[2-5] Detailed observation of this interference in fact might lead to a measurement of the relative production phase of the f^0-A_2.

High-mass bosons produced in the $\bar{N}N$ direct channel and decaying into $K\bar{K}$ final states might provide another example of such interference effects.[6] The speculated existence of meson towers with approximately equal numbers of $I=0$ and $I=1$ mass-degenerate states could further facilitate interference.[7] Furthermore, in this case, the production mechanism could be the same and the interfering effects might be large. The study of low-energy $\bar{N}N\to K\bar{K}$ scattering has progressed to the point where it is now reasonable to ask whether there is any evidence for such interference phenomena. In this note we compile and analyze the available data.[8,9] We find evidence that such interference does occur. Furthermore, we infer the existence of two high-mass boson states with $C=+1$

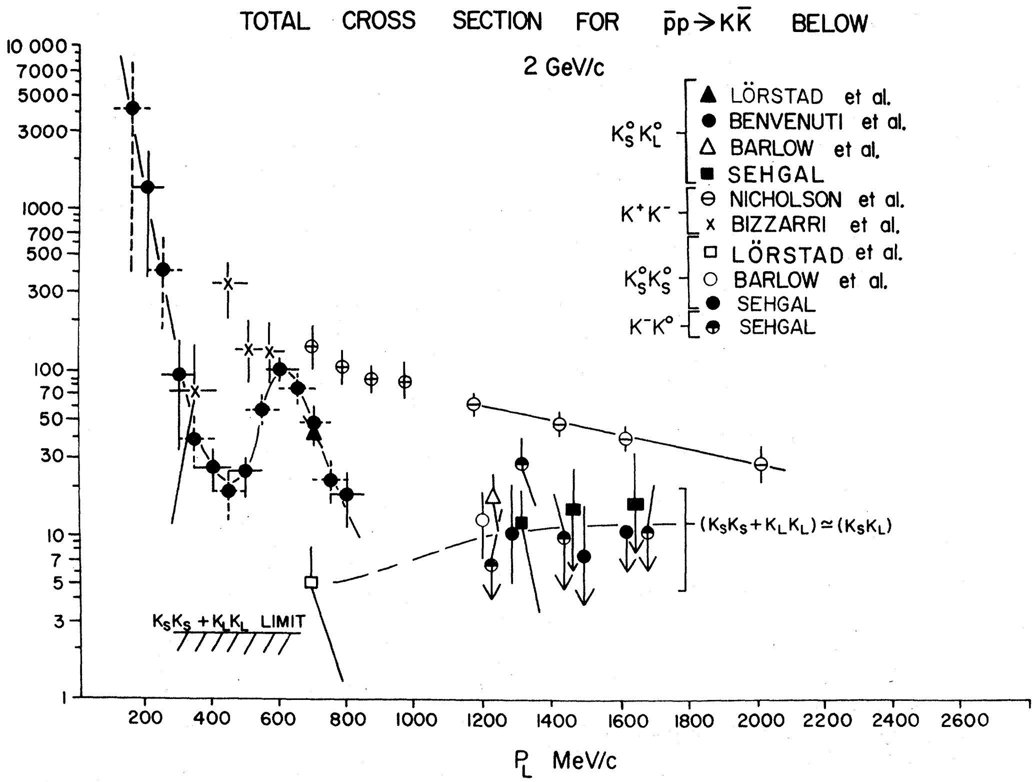

FIG. 1. Compilation of the available cross sections for reactions (1), (2), (3), and (4) for laboratory momenta below 2 GeV/c. The data are taken from Refs. 8 and 9.

and $J^P=2^+$ as a result of this interference.

The reactions we present data on are

$$\bar{p}p\rightarrow K^+K^-, \tag{1}$$

$$\bar{p}p\rightarrow K_S^0K_L^0, \tag{2}$$

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

$$\bar{p}n\rightarrow K^-K_S^0. \tag{4}$$

In Fig. 1 we show the existing data available to us for the cross sections of these processes up to ~2 GeV/c antiproton momentum.[8] The striking features evident in these data are the following:

(1) Below 1000 MeV/c the cross section for $K_SK_S+K_LK_L$ production is much smaller than either the cross section for the reaction K^+K^- or K_SK_L. It is two orders of magnitude less than the K^+K^- in the 400–500-MeV/c band.

(2) The $K_S^0K_L^0$ cross section shows a pronounced structure. This structure has been interpreted elsewhere as evidence for a new vector-meson state with mass 1970 MeV and width of 35 MeV.[9]

(3) The cross section for K^+K^- production is *always* greater than the sum of the cross section for $K_SK_S+K_LK_L+K_SK_L$ production over the entire momentum range.

(4) Above ~1200 MeV/c, within the rather poor statistics, the cross sections for $K_SK_S+K_LK_L$ and K_SK_L are the same.

We further note that the K_SK_L system has been shown to be dominantly produced through the $^3D_1$ initial $\bar{N}N$ state in the momentum range 500–700 MeV/c and that the $K_SK_S+K_LK_L$ system can be produced through the initial states $^3P_0$ or $^3P_2$.[8,9] Thus, the centrifugal barrier favors the production of $K_SK_S+K_LK_L$ over K_SK_L.[6]

There are adequate data available for reactions (1) and (2) to fit the angular distributions to a Legendre-polynomial expansion. In Figs. 2 and 3 we present the even Legendre coefficients for reactions (1) and (2), respectively, in the form of the ratios a_n/a_0.[8,9] While the a_2/a_0 coefficients for these two reactions behave similarly, the a_4/a_0 are quite different. In particular, the K^+K^- system requires large positive a_4/a_0 with the a_4/a_0 showing possible energy-dependent structure. For the K_SK_L system, the a_4/a_0 coefficients are consistent with being zero everywhere and if not zero, negative at 700 MeV/c.[9] This qualitative difference and the larger K^+K^- cross section are strongly suggestive that both $C=+1$ and $C=-1$ states contribute to the K^+K^- system.

Furthermore, an asymmetry is observed between the K^+K^- forward and backward angular distribution

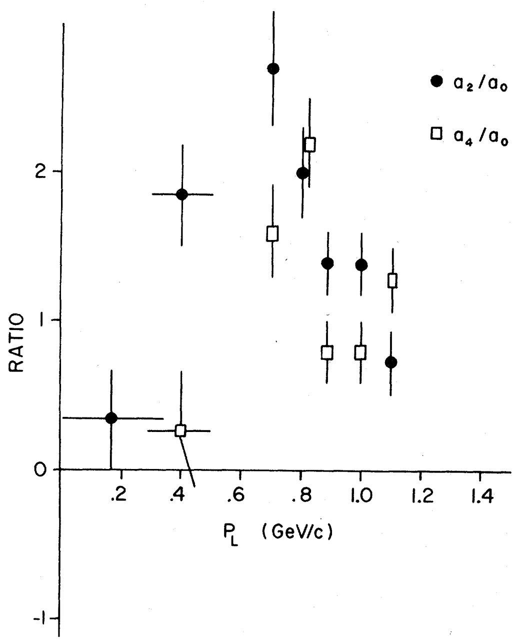

FIG. 2. Even Legendre coefficients for $\bar{p}p \to K^+K^-$ below 1.2 GeV/c. For the two lowest energies the coefficients were obtained by us through fits to the published angular distributions. The other data are taken directly from the report of Nicholson *et al.* (Ref. 8).

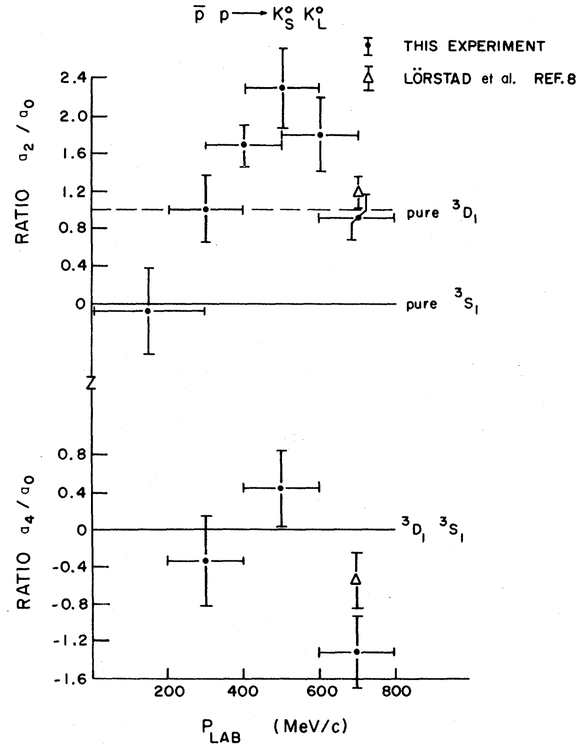

FIG. 3. Even Legendre coefficients for $\bar{p}p \to K_SK_L$ taken from the paper of Benvenuti *et al.* (Ref. 9).

by Bizzarri *et al.* in the 400-MeV/c momentum range indicating the presence of $C=+1$ and $C=-1$ interference.[8,10]

These arguments plus the plausible physical expectation that the $^3P_0$ and $^3P_2$ initial states in the $\bar{N}N$ system should be important if the $^3D_1$ state is important, lead to the conclusion that the $C=+1$ state contributes equally or greater to the K^+K^- system than the $C=-1$. Thus, the suppression of the $K_SK_S+K_LK_L$ process which is pure $C=+1$ requires strong destructive interference. Furthermore, the energy-dependent structure in a_4/a_0 for K^+K^- suggests that there is structure in $J^P=2^+$, i.e., the $^3P_2$ $\bar{N}N$ initial state. The destructive interference in $K_SK_S+K_LK_L$ must therefore also occur largely in the 2^+ state.

We now briefly attempt to make our arguments more quantitative. A general partial-wave analysis is clearly impossible with the limited data that presently exist. Therefore, we present here a simple model which reproduces the general features of the data and which indicates the plausibility of the interference arguments given above. The amplitude for reactions (1), (2), and (3) are written as

$$A(\bar{p}p\to K^+K^-)=A_1^+ + A_0^+ + A_1^- + A_0^-\,, \tag{5}$$

$$A(\bar{p}p\to K_SK_L)=A_1^- - A_0^-\,, \tag{6}$$

$$A(\bar{p}p\to K_SK_S+K_LK_L)=A_1^+ - A_0^+\,, \tag{7}$$

where $A_{1,0}^+$ and $A_{1,0}^-$ represent the $C=+1$ and $C=-1$, $I=1,0$ amplitudes. It is straightforward to express these amplitudes in a general partial-wave expansion; however, for simplicity we assume that for the $C=-1$ amplitude only the $^3S_1$, $^3D_1$ initial states contribute. Furthermore, we consider that a particular isospin state dominates the $^3D_1$ amplitude because of the resonant structure shown in Fig. 1. We assume that the $^3S_1$ contribution is negligible above 400 MeV/c since reaction (2) suggests nearly complete dominance of the $^3D_1$ state.[8,9] Furthermore, since annihilation at rest indicates that[11]

$$\mathrm{Rate}(\bar{p}p\to K^0_SK^0_L)\sim \mathrm{Rate}(\bar{p}p\to K^+K^-)\,, \tag{8}$$

we suspect that either the $I=1$ or $I=0$ state dominates the $^3S_1$ amplitude and that the small $^3S_1$ amplitude required for reaction (2) is *not* due to an accidental cancellation of the $I=0$ and $I=1$ amplitudes in (6).[12] With these assumptions the resulting cross sections for reactions (1) and (3) are given as

$$\sigma(\bar{p}p\to K^+K^-)=|A_1^+ + A_0^+|^2+\sigma(\bar{p}p\to K^0_SK^0_L)\,, \tag{9}$$

$$\sigma(\bar{p}p\to K^0_SK^0_S+K^0_LK^0_L)=|A_1^+ - A_0^+|^2\,. \tag{10}$$

The data of Fig. 1 therefore indicate that

$$|A_1^+ + A_0^+|^2 > \sigma(\bar{p}p \to K_S K_L), \qquad (11)$$

$$|A_1^+ + A_0^+|^2 \gg |A_1^+ - A_0^+|^2, \qquad (12)$$

at all momenta below 800 MeV/c except perhaps near 600 MeV/c where the $K_S^0 K_L^0$ cross section approaches the K^+K^- cross section. Clearly improved data for the K^+K^- cross section would be needed to obtain the energy dependence of $|A_0^+ + A_1^+|^2$ (within the framework of this model). Qualitatively, the conclusions from this model strengthen the previous conclusions that the $C = +1$ amplitudes are very important and that the suppression of the $K_S K_S + K_L K_L$ cross section is due to a cancellation between the $I=1$ and $I=0$, $C=+1$ amplitudes. If we assume that the $C=+1$ state is dominated by $I=0$ and $I=1$ resonance production in the $^3P_2$ initial state (in agreement with the angular distribution shown in Fig. 2), then the amplitudes for these states must be approximately in phase and the masses and widths should be approximately the same. *We know of no a priori reason for such a remarkable phase relationship between direct-channel states.* Furthermore, in the simple meson-tower picture there are six possible resonance states in this mass range that could contribute to the $C=+1$ amplitude, namely,[6,7]

0^+ $I=0,1$ $(^3P_0)$,

2^+ $I=0,1$ $(^3P_2, {}^3F_2)$,

4^+ $I=0,1$ $(^3F_4, {}^3H_4)$.

Thus, if all these states couple to the $\bar{N}N \to K\bar{K}$ system, the resulting amplitudes would be required to be in phase or a complicated accidental cancellation would be required. We suspect that detailed study of this interference phenomenon will shed considerable light on the meson-tower hypothesis and the couplings of these states to the $\bar{N}N$ and $K\bar{K}$ channels.

Finally, we turn to the data above 1.2 GeV/c. It was suggested some time ago that if baryon exchange mediates the $\bar{p}p \to K\bar{K}$ reactions, the cross sections for reactions (2) and (3) would be the same.[13] The data appear consistent with this trend. Thus it may be that the effects of baryon exchange are observable even at this low momentum. We note that there is other evidence to support this possibility.[14] It is therefore likely that the direct-channel production does not dominate the $K\bar{K}$ production in this momentum range and that the striking interference phenomena discussed in this note will be limited to low energies.

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[2]The f^0 is observed to be produced by π exchange and the A_2 by ρ exchange.

[3]It is likely necessary to study three out of four of the processes $\pi^-p \to K^+K^-n$, $\pi^-p \to K_S^0K_S^0n$, and $\pi^-p \to K_SK_Ln$ or $\pi^-p \to K_S^0K^-p$ in the vicinity of the f^0-A_2 mass in order to observe the interference. So far, experimentally these final states have not been carefully studied at any one energy. However, it does appear that a bump is observed in the mass spectrum for *both* K^+K^- and K_SK_S final states at the energies where these reactions have been studied indicating that the interference effects are not large. See Ref. 4 for data on the K_SK_S final state and Ref. 5 for data on the K^+K^- final state.

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[5]See, for example, B. D. Hyams *et al.*, Nucl. Phys. B22, 189 (1970).

[6]D. Cline, in a talk given at the Argonne National Laboratory Workshop on Meson Spectroscopy (unpublished); University of Wisconsin report (unpublished).

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[9]A. Benvenuti *et al.*, Phys. Rev. Letters 27, 283 (1971).

[10]Preliminary data from a Wisconsin experiment studying $\bar{p}p \to K^+K^-$ confirm the different forward and backward hemisphere angular distributions.

[11]C. Baltay *et al.*, Phys. Rev. Letters 17, 207 (1965).

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[13]V. Barger and D. Cline, Phys. Letters 25B, 415 (1967).

[14]B. Barish *et al.*, Phys. Rev. Letters 23, 607 (1969).