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$\bar{p}$-p Annihilations to K and π Mesons at 2.7 GeV/c

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We report results on the reactions $\bar{p}+p \rightarrow K+\bar{K}+n\pi$ $(n=1, 2, \cdots)$ at 2.7 GeV/c. The cross section for this process is estimated to be 4.1 ± 0.6 mb. Comparison of 2.7-GeV/c partial cross sections with data at 3.0 and 3.7 GeV/c indicates that these partial cross sections either are relatively constant or slowly decrease with energy. $K^*(890)$ production is observed in all the four-, five-, and six-body final states. The production of ρ^0 and ω^0 is also observed. The $K\bar{K}$ mass spectra show enhancements near threshold as has been seen in other $\bar{p}$-p experiments. The present data cannot distinguish between a resonance or S-wave scattering-length interpretation of these enhancements. No significant evidence for resonances decaying into $K\pi\pi$ or $K\bar{K}\pi$ was observed.

I. INTRODUCTION

THE annihilations of antiprotons to kaons and pions in the final state have been studied over a wide momentum range from rest to 7 GeV/c.[1–9] In a continuing study[10–14] of antiproton-proton interactions at 2.7 GeV/c we have studied the production of kaons and pions in those topologies in which at least one neutral kaon was observed to decay in the bubble chamber via the $K_1^0 \rightarrow \pi^+\pi^-$ decay mode. Since the separation of charged kaons and pions on the basis of ionization is poor for laboratory momenta above 600–700 MeV/c, events which did not have a visible $K_1^0 \rightarrow \pi^+\pi^-$ associated with them were not used.

For those final states with adequate statistics we have studied the production of the well-known resonant states such as $K^*(890)$, ρ, and ω mesons. $K^*(890)$ production is observed in all final states with the exception of the $K\bar{K}\pi$ final state. This is in agreement with similar studies at nearby energies.[6,7] The amounts of resonance production for these final states are given. We have also conducted a search for resonant states decaying to $K\bar{K}$, $K\bar{K}\pi$, or $K\pi\pi$. Cross sections for all observed final states have been obtained and are tabulated.

II. EXPERIMENTAL PROCEDURE

Approximately 91 000 pictures of antiproton-proton interactions were taken in the Brookhaven National Laboratory 20-in. hydrogen bubble chamber. The electrostatically separated antiproton beam was obtained from antiprotons produced in an internal target in the Brookhaven alternating gradient synchrotron. Two stages of electrostatic separation were employed. Details on the separated beam are in the literature.[15] The purity of the beam was greater than 99% as determined by a δ-ray analysis. The beam momentum was 2.7 GeV/c,[13] with a half-width at half-maximum of 0.07 GeV/c.

The film was divided between Iowa State University and the University of Colorado, with Iowa State's

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TABLE I. Distribution of events among various topologies.

Topology	No. events with K_1^0 fit	No. unique constrained events[a]	No. ambiguous constrained events	No. unique unconstrained events[a]	No. ambiguous unconstrained events
0 prong+1 vee	50	...	...	50	...
0 prong+2 vee	10	...	...	10	...
2 prong+1 vee	440	124	80	161	76
2 prong+2 vee	68	52	...	16	...
4 prong+1 vee	226	166	45	15	...

[a] Constrained events refer to those events with either a 1*C* or 4*C* fit. Unconstrained events have no over-all fit, since they have more than one missing neutral particle.

portion containing 44 100 frames and Colorado's 47 200 frames. The separate sections of the film were scanned and measured at the respective institutions. Similar reconstruction and fitting programs were used on the two separate samples of film.[16]

In order to determine that the two sections of film could be combined for subsequent analysis, a check was made to see that various distributions associated with the selected events were in agreement. Such quantities as the distribution of events along the beam path, distribution of flight path length before decay for the neutral kaons, distribution of neutral kaons about the beam direction, χ^2 distributions associated with the various reactions, and other tests were performed. These distributions were found to be in agreement and the data from the two separate institutions were combined and treated as one.

Events were rejected if either the production or decay vertex of the neutral kaon (from here on referred to as "vee") was not located in the fiducial volume defined by $4.0 \leq x \leq 15.5$ in., $2 \leq y \leq 8$ in., and $2 \leq z \leq 8$ in. The bubble chamber was $20 \times 10 \times 10$ in. Our coordinate system was chosen with the origin at the entrance window of the chamber, such that x is nearly along the beam direction, y is in the downward direction, and z is in the direction of the magnetic field of the chamber. It was further required that the vee decay vertex must be ≥ 0.25 in. from the production vertex of the event. This was used in order to eliminate the scanning bias which can occur for vees that decay close to the production vertex. Limits were also placed on the azimuthal angle θ_{az} ($\tan\theta_{az} = p_y/p_x$) and the dip angle θ_{dip} ($\tan\theta_{dip} = p_z/p$) for the incoming beam tracks. These limits were obtained from a large sample of two-prong and four-prong events which had previously been measured. An event was rejected if the angles associated with that beam track did not lie within the following limits:

$$\theta_{az} = (-1.61 - 0.29X \pm 1.4)^\circ,$$
$$\theta_{dip} = (+0.50 \pm 4.0)^\circ,$$

where X is the x coordinate of the production vertex in inches.

Table I shows a topological tabulation of the events which were successfully measured and had a $K_1^0 \rightarrow \pi^+\pi^-$ fit to the associated vee. For an event to be classified as a particular final state, the ionization of all tracks in the event was required to be consistent with the corresponding particle assignments to those tracks from the kinematic fitting program. As seen from Table I, a large fraction of the events was ambiguous. This was due to the fact that a substantial number of the annihilation

TABLE II. $\bar{p}$-p annihilation cross sections to kaons and pions at 2.7 GeV/*c*.

Reaction	σ (mb)
$\bar{p}+p \rightarrow K_1^0+$missing mass[a]	1.6 ±0.2
$\bar{p}+p \rightarrow K^0+\bar{K}+n\pi$ and $\bar{K}^0+K+n\pi$ ($n=1, 2, \cdots$)	0.75±0.15[b]
$\bar{p}+p \rightarrow K+\bar{K}+n\pi$	4.1 ±0.6[b,c]
$\bar{p}+p \rightarrow K^++K^-$	$0.003_{-0.003}^{+0.006}$[d] (90% confidence)
$\bar{p}+p \rightarrow K^0+\bar{K}^0$	<0.01[e]
$\bar{p}+p \rightarrow K^*+\bar{K}$ and $\bar{K}^*+K$	<0.01
$\sigma(\bar{p}+p \rightarrow K+\bar{K}+n\pi)$ / $\sigma(\bar{p}+p \rightarrow$ all annihilations) $= (9.4\pm2.1)\%$	

[a] Missing mass refers to events from all topologies listed in Table I.
[b] Assumes that K^0 and $\bar{K}^0$ are composed of 50% K_1^0 and 50% K_2^0.
[c] Calculated with the assumption that K^+K^-, $K^+\bar{K}^0$, K^0K^-, and K^0K^0 are produced with equal probability.
[d] See Ref. 14.
[e] No events observed. See Ref. 14.

[16] The reconstruction program used was DATPRO, and the kinematic fitting program was GUTS.

TABLE III. Partial cross sections for $\bar{p}$-p annihilations to kaons and pions at 2.7 GeV/*c*.

Final state	Topology	No. unique events	σ (μb)
$K_1^0K^\pm\pi^\mp$	2 prong+1 vee	15	32±13
$K_1^0K^\pm\pi^\mp\pi^0$	2 prong+1 vee	47	175_{-20}^{+40}
$K_1^0(\bar{K}^0)\pi^+\pi^-$[a]	2 prong+1 vee	53	200_{-30}^{+45}
$K_1^0K_1^0\pi^+\pi^-$	2 prong+2 vee	16	36±16
$K_1^0K_1^0\pi^+\pi^-\pi^0$	2 prong+2 vee	35	69±21
$K_1^0K^\pm\pi^\mp\pi^+\pi^-$	4 prong+1 vee	70	151±26
$K_1^0K^\pm\pi^\mp\pi^+\pi^-\pi^0$	4 prong+1 vee	74	182_{-27}^{+32}
$K_1^0(\bar{K}^0)\pi^+\pi^+\pi^-\pi^-$[a]	4 prong+1 vee	20	70_{-16}^{+24}

[a] $(\bar{K}^0)$ indicates an unobserved neutral kaon, either K^0 or $\bar{K}^0$. The unobserved kaons consist of K_1^0's decaying outside the chamber and K_2^0 decays.

TABLE IV. Resonance production at 2.7, 3.0, and 3.7 GeV/c.

Final states	No. $K\pi$ combinations per event with $\lvert I_z \rvert = \frac{1}{2}$	% resonance production/event $K^*(890)$ 2.7	$K^*(890)$ 3.0	$K^*(890)$ 3.7	ρ 2.7	ρ 3.0	ρ 3.7	ω 2.7	ω 3.0	ω 3.7
$K_1{}^0K^{\pm}\pi^{\mp}\pi^0$	4	40±15	15±10	45±15	7±7	10±20	8±8	...	...	...
$K_1{}^0K_1{}^0\pi^+\pi^-\pi^0$	4[a]	40±10	50±20	30±15	10±5	40±20	40±15	6± 6	0	5± 5
$K_1{}^0K^{\pm}\pi^{\mp}\pi^+\pi^-$	4	75±15	60±15	75±15	40±10	35±10	25±10	...	...	...
$K_1{}^0K^{\pm}\pi^{\mp}\pi^+\pi^-\pi^0$	6	50±15	60±10	50±10	15±15	50±20	30±10	30±10	15±5	20±10

[a] Although there are only four combinations/event with $\lvert I_z \rvert = \frac{1}{2}$, since we cannot determine whether the $K_1{}^0$ is from K^0 or $\bar{K}^0$, all six $K_1{}^0\pi$ combinations/event were plotted. Two of these combinations will have $\lvert I_z \rvert = \frac{3}{2}$, but these two combinations should have a phase-space distribution.

events have tracks whose momenta are too high to reliably separate kaons from pions on the basis of ionization.

The uniquely identified events listed in Table I were used to study resonance production. The ambiguous events were used in cross-section determinations as explained in Sec. III.

III. CROSS SECTIONS

In order to obtain cross sections for the various final states, corrections had to be made for the loss of events due to the $K_1{}^0$'s decaying outside the fiducial volume or into neutral particles. The probability of each $K_1{}^0$ decaying inside the fiducial volume was obtained; this then represents the detection probability for a given event. Each event was assigned a weight W_i equal to the inverse of its detection probability. This weight is given by

$$W_i = \tfrac{3}{2}[\exp(-t_{\min}/\tau) - \exp(-t_{\max}/\tau)]^{-1},$$

where

$$t/\tau = (mc^2/Pc)(L/\tau c).$$

We have taken the rest mass of the $K_1{}^0$ to be 497.8 MeV and the mean proper lifetime τ of the $K_1{}^0$ to be 0.87×10^{-10} sec. P is the laboratory momentum of the $K_1{}^0$, $L_{\min} = 0.25$ in., and $L_{\max}$ is the distance along the $K_1{}^0$ flight path to the boundary of the fiducial volume. The factor $\frac{3}{2}$ in W_i takes into account the $K_1{}^0$ charged to total decay ratio of $\frac{2}{3}$. The total weighted number of

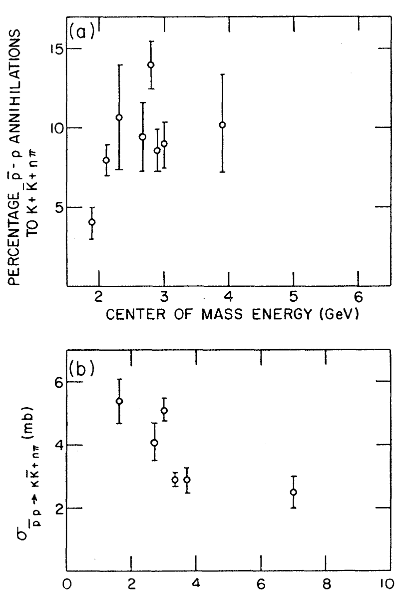

FIG. 1. (a) Percentage of kaonic annihilations (Refs. 6–8, 20) relative to all annihilations as a function of the center-of-mass energy. The center-of-mass energy for 2.7-GeV/c $\bar{p}$-p is 2.67 GeV. (b) $\sigma(\bar{p}+p \to \bar{K}+Kn\pi)$ as a function of incident beam momentum (Refs. 6–8, 20).

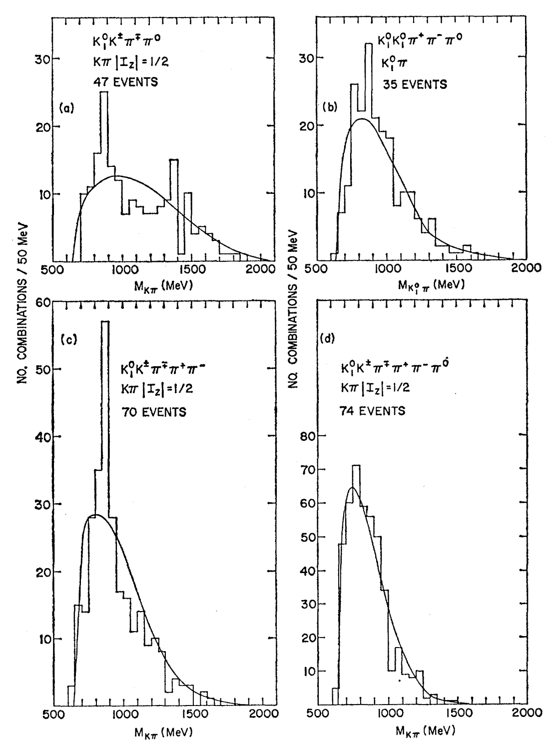

FIG. 2. $\lvert I_z \rvert = \frac{1}{2}$ $K\pi$ effective mass distributions for four-, five-, and six-body final states [reactions (1)–(4)]. Solid curve is Lorentz-invariant phase space normalized to the total number of events.

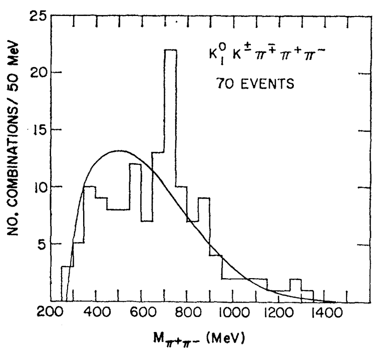

FIG. 3. $\pi^+\pi^-$ effective mass distribution for events from the five-body final states $\bar{p}+p \to K_1{}^0K^\pm\pi^\mp\pi^+\pi^-$.

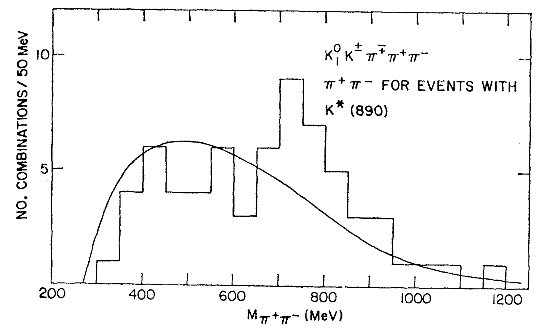

FIG. 5. $\pi^+\pi^-$ effective mass distribution for events from $\bar{p}+p \to K_1{}^0K^\pm\pi^\mp\pi^+\pi^-$ which have a $K\pi$ combination lying in the $K^*(890)$, $850 \leq M(K\pi) \leq 930$ MeV. The π associated with the $K^*(890)$ is not plotted.

events N is given by the relation

$$N=\sum_i W_i \pm \left(\sum_i W_i^2\right)^{1/2}.$$

The weights ranged from 1.68 to 4.60. An average event had a weight of 2.1. One event with unit weight would correspond to 0.9 μb.

In determining the cross sections shown in Tables II and III, we first computed the cross sections for the two sets of data from the two institutions separately. All cross sections were found to be in agreement, and the data were combined and the cross sections in Tables II and III were obtained from the combined data. These cross sections have also been corrected for scanning efficiency and events which failed to reconstruct. In calculating the cross sections, statistical errors for the number of events were used. No attempt has been made to extract the cross section for annihilations to four kaons. At 3.7 GeV/c,[7] it was found to be 31_{-23}^{+40} μb.

In calculating the partial cross sections in Table III, both unique and ambiguous events were used. The ambiguous events were assumed to be distributed within a particular topology, in the same ratio as the unique events. The use of this method is reflected in the asymmetric errors associated with some of the partial cross sections. A comparison of the present data with data at[6] 3.0 and at[7] 3.7 GeV/c shows that the partial cross sections listed in Table III remain relatively constant or in some cases slowly decrease with energy over the momentum range 2.7–3.7 GeV/c.

The fraction of $\bar{p}$-p annihilations to kaons to all annihilations was found to be $(9.4\pm2.1)\%$. The total $\bar{p}$-p annihilation cross section was determined by subtracting the elastic,[12] charge-exchange,[17] single-, and double-pion production without annihilation,[11,18] and hyperon-antihyperon[13] cross sections from the total $\bar{p}$-p cross section.[19] The fraction $(9.4\pm2.1)\%$ at 2.7 GeV/c is in agreement with other results in the range 2–7 GeV/c. This fraction rises from approximately 4% for annihilations at rest, to a constant value of approxi-

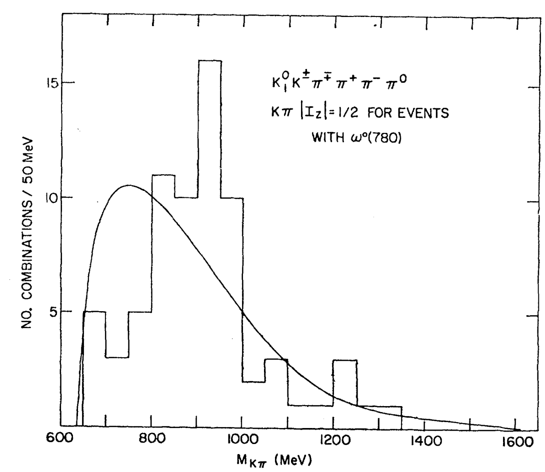

FIG. 6. $|I_z|=\frac{1}{2}$ $K\pi$ effective mass distribution for events from $\bar{p}+p \to K_1{}^0K^\pm\pi^\mp\pi^+\pi^-\pi^0$ having a $\pi^+\pi^-\pi^0$ combination lying in the $\omega^0(780)$, $730 \leq M(\pi^+\pi^-\pi^0) \leq 830$ MeV.

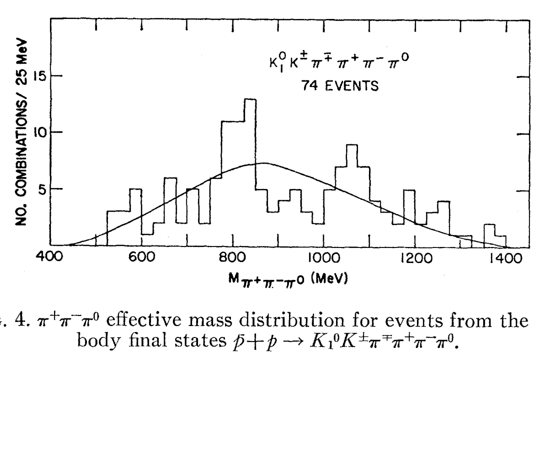

FIG. 4. $\pi^+\pi^-\pi^0$ effective mass distribution for events from the six-body final states $\bar{p}+p \to K_1{}^0K^\pm\pi^\mp\pi^+\pi^-\pi^0$.

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[19] $\sigma_{\text{tot}} \sim 80$ mb at 2.7 GeV/c: R. J. Abrams, R. L. Cool, G. Giacomelli, T. F. Kycia, B. A. Leontic, K. K. Li, and D. N. Michael, Phys. Rev. Letters **18**, 1209 (1967).

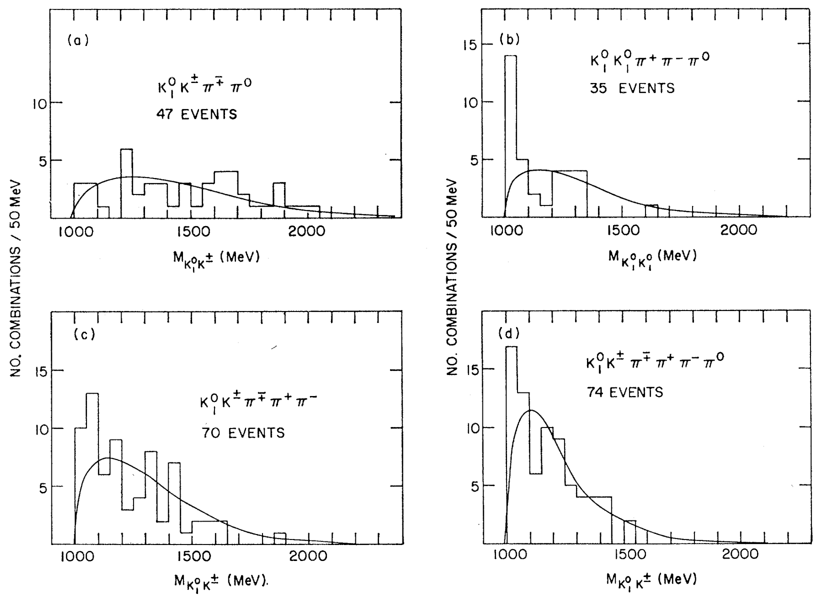

FIG. 7. $K\bar{K}$ effective mass distributions for events from the four-, five-, and six-body final states. All phase-space curves are normalized to total number of events.

mately 10%. In Fig. 1 are shown the available data on kaonic annihilation cross sections and the relative percentage of kaonic annihilations.[6–8,20]

IV. RESONANCE PRODUCTION: $K^*(890)$ ρ AND ω

For the study of resonance production we have used only the four-, five-, and six-body final states with adequate statistics; these final states are

$$\bar{p}p \rightarrow K_1^0K^\pm\pi^\mp\pi^0 \quad (1)$$

$$\rightarrow K_1^0K_1^0\pi^+\pi^-\pi^0 \quad (2)$$

$$\rightarrow K_1^0K^\pm\pi^\mp\pi^+\pi^- \quad (3)$$

$$\rightarrow K_1^0K^\pm\pi^\mp\pi^+\pi^-\pi^0. \quad (4)$$

In each of the samples only unique events have been used.

In this section we present the production rate for the meson resonances present in the data. These rates were obtained by fitting the appropriate effective mass distribution to a curve consisting of the product of a Lorentz-invariant phase-space factor times a Breit-Wigner distribution with an energy-independent width plus a term to take care of the phase-space contribution. The reflections of other resonances have been considered where appropriate. Table IV contains the results from fitting the effective mass distributions, along with results taken from the 3.0- and 3.7-GeV/c $\bar{p}$-p experiments.

[20] Several of the data points shown in Fig. 1 were obtained from L. Agnew, T. Elioff, W. B. Fowler, R. L. Lander, W. M. Powell, E. Segrè, H. M. Steiner, H. S. White, C. Wiegand, and T. Ypsilantis, Phys. Rev. **118**, 1371 (1960); S. Goldhaber, G. Goldhaber, W. M. Powell, and R. Silberberg, *ibid.* **121**, 1525 (1961); N. Xuong and G. R. Lynch, *ibid.* **128**, 1849 (1962); T. Ferbel, A. Firestone, J. Sandweiss, H. D. Taft, M. Gauilloud, T. W. Morris, A. H. Bachmann, P. Baumel, and R. M. Lea, *ibid.* **137**, B1250 (1965).

A. $K\pi$ Mass Distributions

Figure 2 shows the $|I_z|=\frac{1}{2}$ $K\pi$ effective mass distributions for reactions (1)–(4). All final states show substantial $K^*(890)$ production, with the five-body final state of reaction (3) having approximately one $K^*(890)$ per event. As shown in Table IV, substantial production of $K^*(890)$ was also observed in the $\bar{p}$-p experiments at 3.0 and 3.7 GeV/c. The percentage of $K^*(890)$ production for a given final state appears to remain relatively constant over the range 2.7–3.7 GeV/c. No evidence is seen for $K^*(1400)$ production; the enhancement in the 1400–1500-MeV region of raction (1) may be considered to be a statistical fluctuation.

B. $\pi\pi$ Mass Distributions

For the final states investigated, only those of reaction (3) show a sizable ρ signal. The dipion effective mass distribution for reaction (3) is shown in Fig. 3. For reactions (1) and (3) the percentage of ρ appears to remain constant over the momentum range 2.7–3.7 GeV/c. For reactions (2) and (4) the percentage of ρ appears to increase from 2.7 to 3.7 GeV/c.

C. $\pi\pi\pi$ Mass Distributions

Figure 4 shows the $\pi^+\pi^-\pi^0$ effective mass distribution for reaction (4); the production of the ω^0 meson at 780 MeV is apparent. No evidence is seen in these data for the production of the η^0 meson. We note a slight enhancement ($\sim$1 standard deviation) at a mass centered at 1075 MeV in Fig. 4. Although this is in the region of the $A_1(1070)$, we see no evidence for a ρ signal for events from the mass region $1000 \leq M(\pi^+\pi^-\pi^0) \leq 1140$ MeV. Considering the limited statistics and the possibility of reflections from other resonances, we can

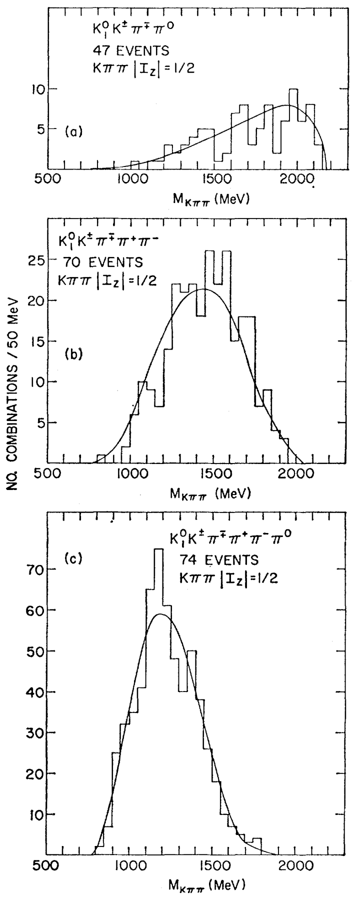

FIG. 8. $|I_z|=\frac{1}{2}$ $K\pi\pi$ effective mass distributions from reactions (1), (3), and (4).

make no further statement about the 1070-MeV mass region. The three-pion mass distributions with an overall charge of ± 1 showed no evidence of a resonance signal.

D. Associated Resonance Production

We have conducted a search among the various five- and six-body final states for the associated production of resonances. No evidence for K^*-$\bar{K}^*$ associated production was observed, other than that expected from the kinematic overlap of the two resonances.

In reaction (3) we have searched for the reaction $\bar{p}+p\rightarrow K^*\rho K$ by displaying the $\pi^+\pi^-$ effective mass distribution for those events which have a $K^*(890)$ defined by $850\leq M(K\pi)\leq 930$ MeV. Figure 5 shows the $\pi^+\pi^-$ mass distribution, from which we estimate the K^*-ρ associated production to be $(15\pm 10)\%$.[21]

[21] In order to estimate the amounts of associated production [$K^*\rho$ in reaction (3) and $K^*\omega$ in reaction (4)], it was necessary to obtain an estimate of the ρ and K^* signals which arise from the nonresonant K^* and ω backgrounds, respectively, which are present when the K^* and ω mass cuts are made. This was done by examining control regions below and above the K^* and ω and using these mass distributions to estimate the nonresonant background contributions.

Reaction (4) was studied for K^*-ω associated production. Figure 6 shows the $K\pi$ effective mass distribution for those events with an ω meson defined by $730\leq M(\pi^+\pi^-\pi^0)\leq 830$ MeV. An enhancement in the region of the $K^*(890)$ is observed, although slightly shifted up in mass. From these data we have estimated the K^*-ω associated production to be $(5\pm 5)\%$,[21] consistent with zero.

V. STUDY OF $K\bar{K}$ SYSTEM

Studies of the $K\bar{K}$ system in $\bar{p}$-p annihilations at other energies have indicated effects near threshold, in the region 1000–1100 MeV. These effects appear to be consistent with a large S-wave scattering length in the $K\bar{K}$ system. Enhancements in the $K_1{}^0K_1{}^0$ mass spectrum have been reported in bubble-chamber[22] and spark-chamber[23,24] studies of the reaction $\pi^-p\rightarrow K_1{}^0K_1{}^0n$. The bubble-chamber data favored an S-wave resonance hypothesis over an S-wave scattering length. Their data were fitted with a mass of $\sim$1070 MeV and a width of $\sim$70 MeV. The two spark-chamber experiments obtained differing results, with the data of Hoang *et al.*[23] fitting the S-wave resonance and S-wave scattering-length hypotheses equally well, while the data of Beusch *et al.*[24] favored the resonance interpretation. An essential difference between the $\bar{p}$-p and π^-p studies of the near-threshold $K\bar{K}$ system is that in the $\bar{p}$-p studies the effect is seen in both the charged and neutral $K\bar{K}$ systems, implying $I=1$. The π^-p studies see the effect only in the neutral $K\bar{K}$ system, implying $I=0$. Clearly, the near-threshold region of the $K\bar{K}$ system is confused at present, and could possibly consist of several effects, both resonances and S-wave scattering lengths.

We have studied the $K\bar{K}$ system in the four-, five-, and six-body final states. Figure 7 shows the $K\bar{K}$ effective mass distributions; only unique events were used.[25] For both the five- and six-body final states, enhancements above phase space are seen in the region 1000–1100 MeV. In particular, for the five-body final states of reactions (2) and (3), enhancements are seen in this region. From the data, it is not completely evident that the $K_1{}^0K_1{}^0$ mass distribution for reaction (2) [see Fig. 7(b)] can be considered to be associated with the enhancement in the $K_1{}^0K^\pm$ mass distribution of reaction (3) [see Fig. 7(c)], since the $K_1{}^0K_1{}^0$ effect appears to be

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shifted below 1050 MeV, whereas the $K_1{}^0K^{\pm}$ effect is centered about 1050 MeV. If the two effects are related, then they imply that the effect is in the $I=1$ $K\bar{K}$ system.

We have fitted both the separate and the combined $K_1{}^0K_1{}^0$ and $K_1{}^0K^{\pm}$ mass distributions for the five-body final states of reactions (2) and (3). These data have been fitted to a Breit-Wigner resonance and also to a simple S-wave scattering-length expression. A satisfactory fit was obtained to the $K_1{}^0K_1{}^0$ mass distribution for a mass of $M=1032\pm20$ MeV and a width of $\Gamma=20\pm5$ MeV. The mass and width for the $K_1{}^0K^{\pm}$ mass distribution was $M=1048\pm15$ MeV and $\Gamma=35\pm25$ MeV. The mass and width for the combined distributions was $M=1040\pm20$ MeV and $\Gamma=35\pm15$ MeV. The question of whether the $K_1{}^0K_1{}^0$ and $K_1{}^0K^{\pm}$ effects are related cannot be resolved from the fits to these separate distributions due to the limited statistics and the errors associated with the fitted mass and width.

When the $K_1{}^0K_1{}^0$ and $K_1{}^0K^{\pm}$ mass distributions were fitted to an S-wave scattering length, scattering-length solutions from 3 to 15 F adequately described both the separate and combined distributions. Thus the present data cannot distinguish between a resonance or S-wave scattering-length interpretation of these enhancements.

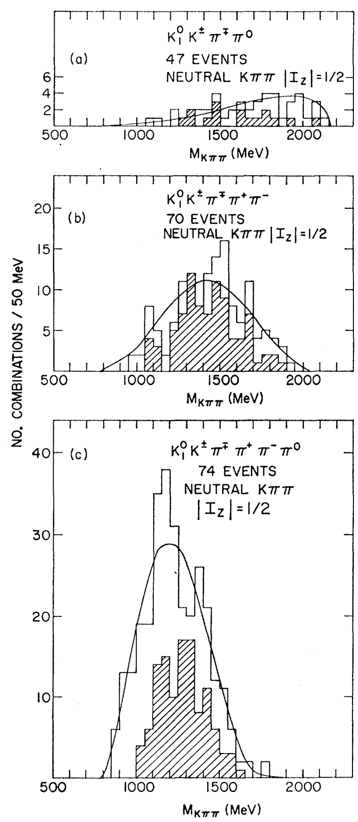

FIG. 9. Neutral $|I_z|=\frac{1}{2}$ $K\pi\pi$ effective mass distribution from reactions (1), (3), and (4). The cross-hatched mass distributions represent $K^*\pi$ and $K\rho$ combinations.

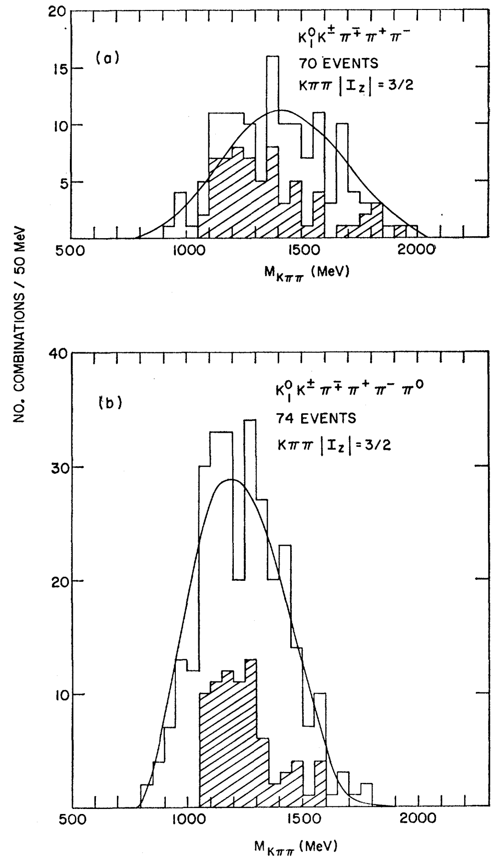

FIG. 10. $|I_z|=\frac{3}{2}$ $K\pi\pi$ effective mass distributions from reactions (3) and (4). The cross-hatched mass distributions represent $K^*\pi$ combinations.

No other enhancements are observed in the data of Fig. 7; in particular, no signal for $f^0\rightarrow K_1{}^0K_1{}^0$ or $A_2{}^0\rightarrow K_1{}^0K_1{}^0$ is seen.

VI. SEARCH FOR $K\pi\pi$ AND $K\bar{K}\pi$ RESONANCES

A study of the $|I_z|=\frac{1}{2}$ $K\pi\pi$ system for resonance production has been conducted in the four-, five-, and six-body final states. Effects in the $|I_z|=\frac{1}{2}$ $K\pi\pi$ system have been reported[26,27] for π^-p interactions; these experiments report an effect for $K\pi\pi$ masses near 1175 MeV. Figure 8 shows the $|I_z|=\frac{1}{2}$ $K\pi\pi$ effective mass distributions for reactions (1), (3), and (4). No evidence for enhancements in the $K\pi\pi$ system is seen, all distributions being adequately represented by phase space. We do note a ~1.5 standard deviation from phase space near 1175 MeV in Fig. 8(c). However, this effect is too broad (~150 MeV) to be the 1175-MeV effect seen in π^-p, which had a reported width of about 50 MeV.

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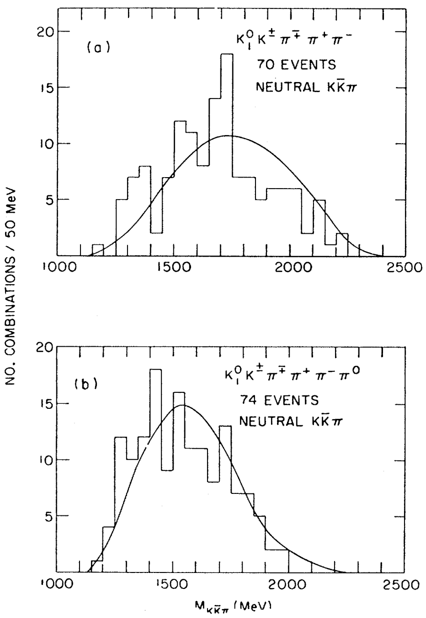

FIG. 11. Neutral $K\bar{K}\pi$ effective mass distributions from reactions (3) and (4).

An enhancement in the neutral $|I_z|=\frac{1}{2}$ $K\pi\pi$ system near 1215 MeV has been reported in $\bar{p}$-p interactions at rest.[28] The results of their analysis showed that this effect decayed via the $K^*\pi$ and $K\rho$ modes. Figure 9 shows our neutral $|I_z|=\frac{1}{2}$ $K\pi\pi$ effective mass distribution; the shaded area represents those events which have a $K^*\pi$ or $K\rho$ combination, where the K^* and ρ are defined by $850\leq M(K\pi)\leq 930$ MeV and $680\leq M(\pi\pi)\leq 820$ MeV. Again, the distributions are well represented by phase space alone.

In a study of the reaction $\bar{p}+p\rightarrow K_1^0K^\pm\pi^\mp\pi^+\pi^-\pi^0$, Böck *et al.*[29] reported on a resonance near 1270 MeV, with $\Gamma\sim 60$ MeV, in the $|I_z|=\frac{3}{2}$ $K\pi\pi$ system. Their analysis indicated that this effect was enhanced for $K^*\pi$ selection. Our data for the same reaction, plus the reaction $\bar{p}+p\rightarrow K_1^0K^\pm\pi^\mp\pi^+\pi^-$, are shown in Fig. 10. The shaded area represents the $K^*\pi$ selection. No significant evidence is seen for an enhancement near 1270 MeV. There is only a difference of approximately 100 MeV between the c.m. energy of the present experiment and Böck *et al.*[29] at 3.0 GeV/c. The experiment of Baltay *et al.*[7] at 3.7 GeV/c reported no evidence for an $|I_z|=\frac{3}{2}$ $K\pi\pi$ resonance near 1270 MeV. One would not expect the production of a resonance in a $\bar{p}$-p annihilation channel to be so energy-dependent.

A resonance at 1410 MeV, $\Gamma\sim 60$ MeV in the neutral $K\bar{K}\pi$ system has been reported for $\bar{p}$-p interactions at rest.[30] In π^-p interactions[31] and $\bar{p}$-p interactions[5] a neutral $K\bar{K}\pi$ resonance has been reported with a mass of 1280 MeV. Figure 11 shows the neutral $K\bar{K}\pi$ effective mass distribution for reactions (3) and (4). No evidence is seen for enhancements near 1280 or 1410 MeV.

VII. CONCLUSIONS

Antiproton-proton annihilations to kaons and pions have been studied at 2.7 GeV/c in those topologies in which a K_1^0 is observed to decay in the charged mode. The annihilation cross section was estimated to be $\sigma(\bar{p}p\rightarrow K\bar{K}+n\pi)=4.1\pm0.6$ mb, in agreement with studies at nearby energies. The partial cross sections for the final states studied when compared with data at 3.0, 3.25, and 3.7 GeV/c were found to be relatively constant or slowly varying with energy. Resonance production in the four-, five-, and six-body final states was studied. All final states showed significant $K^*(890)$ production. Enhancements were seen near threshold in the $K\bar{K}$ system. Both a Breit-Wigner resonance and an S-wave scattering length could be used to explain these enhancements. There was no substantial evidence for resonance production in the $K\pi\pi$ or $K\bar{K}\pi$ systems studied.

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