SEARCH FOR A K^* BELOW $K\pi$ THRESHOLD IN $\bar{p}p$ ANNIHILATIONS AT REST

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(Received 6 August 1968)

An upper limit is given for the two-body annihilations $\bar{p}+p\to K+\bar{K}^*$ $(\bar{K}+K^*)$, where K^* denotes a $J^P=0^+$, $s=+1$ resonance with a mass below $K\pi$ threshold. This upper limit is compared with other two-body annihilation processes.

Recently the rather specific suggestion has been made[1] that there could be a scalar, 0^+, resonant state called κ which would correspond to the strangeness-changing vector current in a way analogous to the pseudoscalar, 0^- pion and the strangeness-conserving, axial-vector current. A way in which such a state could exist with mass near that of the K, yet remain undetected, would be for it to have rest energy below the $K+\pi$ threshold (633 MeV/c^2). This κ, with strangeness $=\pm1$, $I=\frac{1}{2}$, and $J^P=0^+$ could not decay via the strong interaction because of mass-energy conservation, nor to $K\gamma$ via the electromagnetic interaction with order α because of the well-known forbiddeness of $0\to0$ transitions. At order α^2 the decay $\kappa\to K+e^++e^-$ is still inhibited since the single virtual photon needed is forbidden; however $\kappa\to K+\gamma+\gamma$ should proceed and is expected to be the dominant decay mode. Since most experiments are keyed to "no missing neutral" or to a single missing neutral particle, this κ with its two final-state photons indeed would usually fail to be identified. Many bubble-chamber experiments offer an opportunity to detect such a state once settled on the object of the search.[2] Because of the special character of the annihilation of antiprotons stopped in liquid hydrogen,[3] it may be shown that examination of the final state $K_1{}^0K_1{}^0X^0$, where X^0 represents any missing mass (including zero), offers a particularly sensitive way to search for κ if produced in the two-body reaction $\bar{p}+p\to K^0+\bar{\kappa}^0$ $(\bar{K}^0+\kappa^0)$. A sample of 150 events has been examined and no significant "κ signal" has been found (see Fig. 1). Straightforward analysis gives 8×10^{-5} as the upper limit (at 90% confidence level) for the fraction of all $\bar{p}p$ annihilations which yield $K^0\kappa^0$. This result may be compared with the fractional rates for other related final states[4] from the annihilation process (see Table I). The remainder of this communication is concerned with the pertinent details of the investigation and a brief discussion of the implication of the results.

The key fact which makes this search particularly sensitive to the presence of the κ is the freedom from the background which would be caused by the process $\bar{p}+p\to K_1{}^0+K_1{}^0$ if it occurred. Almost all of the $\bar{p}p$ annihilations at rest in a hydrogen bubble chamber correspond to capture from the S state; consequently the final state $K_1{}^0K_1{}^0$ is essentially absent.[5] Following Schwarz,[3] the associated production of one scalar and one pseudoscalar particle can come only from the ${}^1S_0$ state with charge conjugation, C, positive. Since C is conserved in strong and electromagnetic interactions, the final state $K^0K^0\gamma\gamma$ must have C positive; therefore the two K^0's must always occur as $K_1{}^0K_1{}^0$ or $K_2{}^0K_2{}^0$, never as $K_1{}^0K_2{}^0$. When K^0 production occurs from $\bar{p}$'s at rest in the hydrogen and one $K_1{}^0$ decay is detected, the second $K_1{}^0$ is present and will be seen to decay into $\pi^++\pi^-$ approximately $\frac{2}{3}$ of the

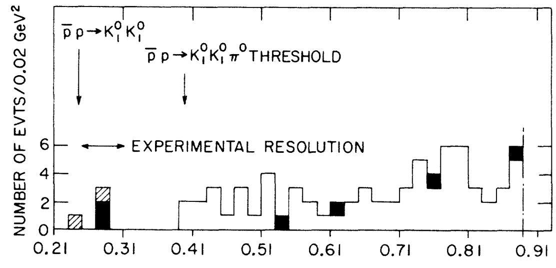

FIG. 1. $M^2(K_1{}^0X^0)$ from $\bar{p}+p\to K_1{}^0+K_1{}^0+X^0$ (two combinations per event). The events with $M(X^0)$ larger than $2\pi^0$ mass have not been plotted. The white, grey, and black cells correspond to $\bar{p}+p\to K_1{}^0+K_1{}^0+\pi^0$, $\bar{p}+p\to K_1{}^0+K_1{}^0$, and events with no "direct" physical interpretation: They can be considered either as $\bar{p}+p\to K_1{}^0+K_1{}^0+\pi^0$ annihilations in flight, or, for the two events with one combination at $M^2(K_1{}^0X^0)=0.28$ GeV^2, as candidates for $\bar{p}+p\to K^0+\bar{\kappa}^0$ $(\bar{K}^0+\kappa^0)$ production.

time.

From the 150 events in this study with two identified K_1^0's and no charged prongs emerging from the initial vertex, one has been identified as $K_1^0K_1^0$, 87 have been identified as $K_1^0K_1^0\pi^0$, 60 have missing mass much too large to be of interest here (MM greater than that of two pions), and three have a small missing mass but do not fit the hypothesis of a single missing π^0. For all of the events except those with large missing mass, the momentum of each K_1^0 as determined in the initial three-constraint fit has been used to construct $M^2(K_1^0X^0)$. The resulting distribution is shown in Fig. 1. Note that there are two $M^2(K_1^0X^0)$ values for each physical event.

The mass-squared region of interest is between $M^2(K^0) = 0.248$ GeV^2 and $[M(K^0)+M(\pi^0)]^2 = 0.4$ GeV^2. There are three events in this interval, all of them with $M^2(K^0X^0)$ very near to 0.28 GeV^2. Such a close coincidence of the value of $M^2(K^0X^0)$ can only be regarded as accidental since our mass resolution is ±30 MeV or ±0.03 GeV^2. In fact, because of our mass resolution, it is reasonable to divide the whole mass interval under study into at most three bins. The probability that three random events all fall into the same bin is then 10% too high to be neglected. We therefore consider 3 to be an upper limit for the number of $K^0\bar{\kappa}^0$ ($\bar{K}^0\kappa^0$) events observed. These three combinations come from three different events: One of them is one of the two combinations associated to the single event which fits $\bar{p}+p\rightarrow K_1^0K_1^0$. The two other combinations are associated with two events for which the second combination falls above 0.4 GeV^2.

The interpretation of these two events as possible candidates for the production $\bar{p}+p\rightarrow K^0+\bar{\kappa}^0$ ($\bar{K}^0+\kappa^0$) is weakened by the fact that these two events can still be interpreted as three-body annihilations $\bar{p}+p\rightarrow K_1^0+K_1^0+\pi^0$ in flight.

These events come from 0.275×10^6 $\bar{p}p$ annihilations; the probability of observing $K^0\bar{K}^0$ decaying to four charged pions in this situation is 0.22; the overall scanning efficiency is 0.87. Combining these numbers we arrive at 8×10^{-5} as the upper limit at 90% confidence level for the fraction of $\bar{p}p$ which can yield $K^0\bar{\kappa}^0$ ($\bar{K}^0\kappa^0$).

This result is compared with the rates of other related two-body reactions in Table I. Indeed the observed upper limit is very low compared with $\pi\pi$, $K\bar{K}$, $K\bar{K}^*$ ($\bar{K}K^*$). However, these states are different from the $K\bar{\kappa}$ ($\bar{K}\kappa$) and are produced most strongly from the triplet initial state, while the $K\bar{\kappa}$ ($\bar{K}\kappa$) can come only from the singlet. One can argue that the comparison should be made only with the production of a single pion with a strong scalar enhancement. The only candidate for this type of reaction is the $K\bar{K}$ enhancement[4] at 1 GeV/c^2, whose production rate is not very different from our upper limit on the $K\bar{\kappa}$ ($\bar{K}\kappa$) rate. Although our result is consistent with there being no κ at all, it does not represent strong evidence against its existence.

Table I. Fractional rates (for relevant final states from stopped $\bar{p}$ in hydrogen).

Final state[a]	Initial state Spin	Initial state Isospin	Fractional rate (10^{-5})
$\pi^+\pi^-$	$^3S_1$	0, 1	320 ± 30
$K^0\bar{K}^0$	$^3S_1$	0, 1	73 ± 3
$K\bar{K}^*$ ($\bar{K}K^*$)	$^1S_0$	0	84 ± 14
	$^1S_0$	1	66 ± 27
	$^3S_1$	0	17 ± 10
	$^3S_1$	1	310 ± 30
$(K\bar{K})\pi$	$^1S_0$	0	10
$K\bar{\kappa}$ ($\bar{K}\kappa$)	$^1S_0$	0, 1	<8

[a] $(K\bar{K})$ stands for a strong enhancement observed near threshold, which can be parametrized by a Breit-Wigner shape with $M = 1016$ MeV (Ref. 4). The rates for $K\bar{K}^*$ ($\bar{K}K^*$) for $^1S_0(I=0,1)$ and for $^3S_1(I=0)$ are given in Ref. 4. The rate for $^3S_1(I=1)$ is obtained by addition of the corresponding rate as observed in $\bar{p}+p\rightarrow K_1^0+K^\pm+\pi^\mp$ (Ref. 4), and the rate deduced from the observation of K^{*0} production in the final state in $\bar{p}+p\rightarrow K_1^0+K_2^0+\pi^0$.

Glashow and Weinberg suggest that if the κ is not found in the mass region explored here, it could still exist in the region $M(\kappa) > 1125$ MeV/c^2. Though it is intriguing to look for the κ in other processes,[2] we feel that this method is particularly free from background. The contribution from $\bar{p}+p\rightarrow K_1^0+K_1^0$ is extremely small and, with larger numbers of events, the signal-to-noise ratio could be much improved by tighter constraints to remove events corresponding to annihilations in flight.

We wish to acknowledge a stimulating discussion with S. Glashow. The work of one of us (E.C.F.) was made possible by the hospitality of CERN and the Institute of Physics at the University of Rome, and by financial support from the American Commission for Cultural Exchange with Italy and from the Duke Endowment.

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*Work done while visiting CERN and the Institute of Physics at University of Rome, Rome, Italy.

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VECTOR DOMINANCE, REGGE POLES, AND π^0 PHOTOPRODUCTION*

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(Received 5 August 1968)

The presently accepted Regge parametrization of π^0 photoproduction claims that the $t\sim-0.5$ BeV^2 cross section is completely provided by B exchange. We show that this statement disagrees with vector dominance by a factor of at least 4 and probably 10 or more. Additional $I=0$ poles or cuts are needed both in this process and in the $I=0$ t-channel combination of $\pi+N\rightarrow\rho+N$ cross sections.

The vector-meson–dominance hypothesis relates pion photoproduction processes to the production of transversely polarized vector mesons in pion-initiated reactions.[1] Recent applications[1] of this idea to π^+, π^-, and π^0 photoproduction indicate that such relations are at least consistent with experiment and in some cases one can even detect significant agreement.

Regge-pole theory can be applied to $\gamma+N\rightarrow\pi+N$ as well as to $\pi+N\rightarrow V+N$ reactions. Many experimental features of these processes require the introduction[2] of significant contributions of "exotic" poles and cuts such as the π', B, and ω' poles, the π-P cut, etc.

The purpose of this note is to suggest that once we accept the vector-dominance hypothesis as a valid principle, we may use it in order to test specific Regge "explanations" of the data. In particular, we point out that the currently accepted parametrization[3] of $\gamma+p\rightarrow\pi^0+p$ in terms of ω and B exchange is in violent disagreement with vector dominance and that an extra $ICG=0^{--}$ exchange term, such as an ω' pole or an ω-P cut, is necessary in order to "explain" this process within the framework of Regge theory. We further show that between these two possibilities the ω-P cut is favored.

The usual Regge description of high-energy π^0 photoproduction runs as follows[3]:

(1) Only $C=-1$ neutral mesons can be exchanged in the t channel. The only established ones are ω, ρ, φ, and B.

(2) The $\varphi\pi\gamma$ coupling is vanishing or extremely small[4]; the $\rho\pi\gamma$ coupling is smaller than the $\omega\pi\gamma$ one; the B trajectory is lower than the ω. Hence, ω exchange should dominate.

(3) A pure Reggeized ω exchange predicts a forward dip in $d\sigma/dt$ (in agreement with experiment) and a zero in $d\sigma/dt$ at the point where $\alpha_\omega(t)=0$.

(4) Since experimentally[5] there is a dip or a "break" but not a zero in the angular distribution around $t\sim-0.5$ BeV^2, there should be another contribution present. Since ρ exchange would also yield a zero at the same t value, the only candidate for contributing to $d\sigma/dt$ at $t=-0.5$ is B exchange.[6] An adequate fit of all angular distributions between $E_\gamma=2$ and 5.8 BeV can be achieved with ω and B exchange.[3]

The simple point that we would like to make here is the following: In the $\omega+B$ exchange model, the entire contribution to $d\sigma(\gamma+p\rightarrow\pi^0+p)/dt$ at the point $\alpha_\omega(t)=0$ must come from B exchange and, therefore, from π^0 photoproduction