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Search for narrow states with baryon number zero and strangeness -1 in $\bar{p}p \to K^+_{\rm slow} X^-$ at 5 GeV/c

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A search for narrow states with baryon number zero and strangeness -1 was conducted in $\bar{p}p$ collisions. These hypothetical states could be composed of two quarks and two antiquarks and are similar to baryonium states. The experiment studied the missing mass recoiling against a slow K^+. No narrow resonances were observed, corresponding to cross-section upper limits of 4 μb for masses below 2.75 GeV/c^2.

Several narrow $N\bar{N}$ states have been reported, generating speculation that these might be four-quark states. These so-called baryonium states have a murky history, since subsequent experiments generally failed to confirm these narrow peaks. A $\bar{p}p$ state at 1.93 GeV/c^2 has been reported by several groups,[1,2] but several more recent experiments have not observed it.[3,4] In 1977, two other narrow $\bar{p}p$ states were reported[5] at 2.02 and 2.2 GeV/c^2. In addition, the 2.02-GeV/c^2 state was observed in a $p\bar{n}$ experiment.[6] However, there are many other experiments that do not observe either of these last two resonances.[2,4,7,8]

If four-quark $N\bar{N}$ (baryonium) states do exist, then it is natural that four-quark states with a net strangeness of -1 should also exist. These states should show up in $\bar{p}p$ interactions where the final state has strange particles. A previous search for $S=+1$ and $Q=+2$ narrow states at first reported a state at 2.46 GeV/c^2 (Ref. 9), but a follow-up experiment[10] with higher statistics did not observe this state. Another previous experiment[11] in a π^- beam at 16 GeV/c looked for narrow $S=-1$, $Q=0$ and $S=-1$, $Q=-2$ states decaying to $\Lambda\bar{p}\pi^\pm$ and put upper limits on the production cross section times branching ratio ranging from about 10 nb at 2.3 GeV to about 40 nb at 2.8 GeV. Our experiment has three inherent advantages over that previous search. First, we have performed a missing-mass search, which extends the mass range over which we can see a resonance to well below the $\Lambda\bar{p}$ threshold, in fact down to 1.1 GeV. Second, we gain about a factor of 10 by measuring cross section instead of cross section times branching ratio. Third, the beam momentum of 5 GeV/c favors the exchange process compared to that of a π^- beam at 16 GeV/c by at least a factor of 10 (assuming that the cross section varies at least as rapidly as P^{-2}, where P is beam momentum).

This experiment conducted a search in the Brookhaven National Laboratory Multiparticle Spectrometer by studying the reaction

$$\bar{p}+p \to K^+_{\rm slow}+X^-$$

at 5 GeV/c, with the K^+ observed by one of two K^+ detectors. This reaction occurs via hyperon exchange. Narrow four-quark states would appear as bumps in the mass spectrum of X^-.

This part of the experiment used the same equipment as the cascade-resonance search previously reported,[12] where five cascade states were detected, which demonstrates our ability to observe narrow resonances and compute cross sections. Computations of the resolution, efficiency, and acceptance of our equipment are virtually identical in both experiments, since the principal difference was the use of a K^- beam instead of a $\bar{p}$ beam, both at the same momentum of 5 GeV/c. A baryonium search using a different trigger during the same $\bar{p}p$ data-gathering process has also been reported elsewhere.[8] Since the equipment and data reduction are discussed in Refs. 8 and 12, only a short description is given here.

Figure 1 shows the Multiparticle Spectrometer (MPS) where the 5-kG magnet contained a 60-cm hydrogen target, six proportional chambers, and 70 planes of spark chambers. The two K^+ detectors (K_A and K_B) were designed to slow down and stop K^+ particles in the momentum range 200 to 600 MeV/c. The K^+ detectors were constructed with ten alternating planes of brass and segmented scintillators, and corresponded to about 100 g/cm^2 of stopping power. K_A was borrowed from Imperial College[13] and had an active area of 60 cm × 100 cm. K_B's active area was 110 cm × 140 cm. The K^+ trigger consisted of the detection of a highly ionizing stopping K^+ and the observation of the subsequent K^+ decay 8 to 50 nsec after the stop. The segmented scintillation planes allowed for the detection of backward as well as forward K^+ decays.

Since the ratio of pions plus protons to K^+'s incident on the detectors was more than 10 000 to 1, some triggers were initiated by π's and protons, due to time jitter. To reduce this background, a software package was developed to correct the phototube time (TDC) as a function of pulse height (ADC). The K detectors were placed in a test beam and TDC versus ADC values were recorded for 10 000 beam particles. It was observed that the smaller the ADC value, the larger the TDC value, i.e., the bigger the pulse height, the sooner (on the average) the first photon arrived at the phototube. The correction corresponded to an average of 3 nsec for the smallest detected pulse height and dropped to zero as the pulse height increased. This computed correction was applied to each TDC value of the data and the trigger logic was then checked with these corrected times. The procedure was as follows: The detection of a stopping K^+ was accomplished by requiring two consecutive planes to have signals and the next two not to have signals, all within a time window of 2.5 nsec. In addition, the decay product was identified as a

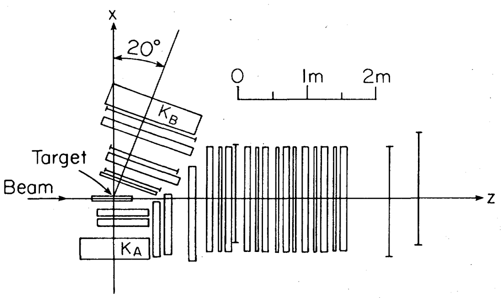

FIG. 1. Multiparticle Spectrometer (top view). K_A and K_B are K^+ detectors, single lines are proportional multiwire chambers, and rectangles are spark chambers. The magnetic field was 0.5 T.

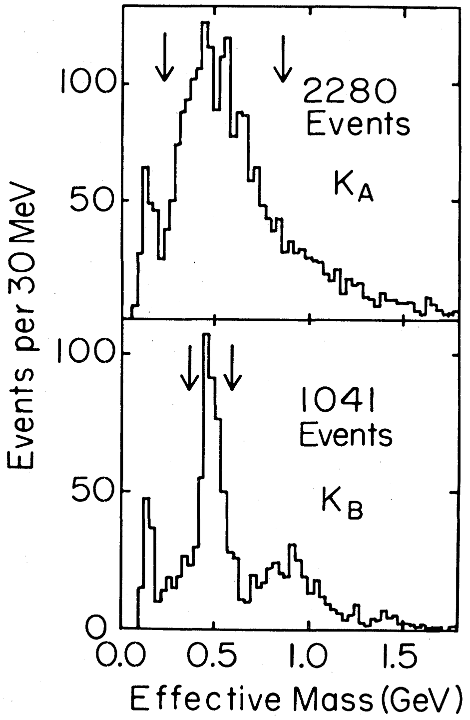

FIG. 2. The mass of particles impinging on the K^+ detectors. The mass is computed from range and curvature information. The arrows show the mass cuts.

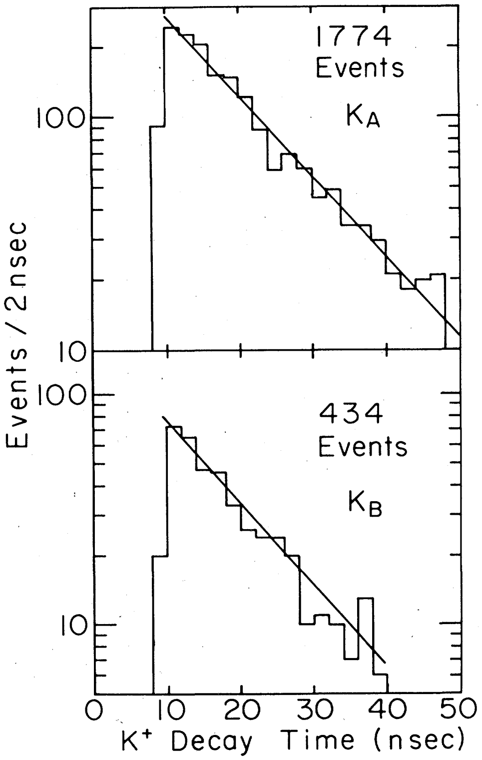

FIG. 3. The decay time of particles within the K^+ mass cuts. The straight lines have a slope corresponding to a lifetime of 12.4 nsec.

TABLE I. Experimental resolution and sensitivity (95% confidence level) for each K^+ detector.

Mass of X^- (GeV/c^2)	Full width at half maximum (MeV/c^2) K_A	K_B	Sensitivity (μb) K_A	K_B
1.25	125		4.0	
1.50	100		3.7	
1.75	50	90	3.3	10.0
2.00	25	60	2.0	6.0
2.25	25	35	3.0	3.1
2.50		35		2.6
2.75		35		2.3

coincidence (within 2.5 nsec) of three or more planes, 8 to 50 nsec after the stopped K^+. About 80% of the triggers initiated by π's and protons failed these tests, while less than 5% of the real K^+'s were lost.

The mass of each trigger particle was computed from the momentum measurement of the tracking chambers and the range measurement of the K^+ detectors. Figure 2 shows the masses of the particles incident on each K^+ detector that satisfied the hardware and software requirements. The K^+ peaks are clearly evident, with small backgrounds. The K mass peak of K_B is much narrower than that of K_A because the momentum measurement of K^+'s on the K_B side was more accurate than on the K_A side due to the longer path length. The final K^+ selection was a mass cut of 250 to 900 MeV/c^2 for K_A and 400 to 600 MeV/c^2 for K_B. Figure 3 shows the decay lifetime of the particles within the K^+ mass cuts. Clearly the slope is the K^+ lifetime. For the events within the K^+ mass selection, a fitted averaged momentum was computed using the momentum information from both curvature and range, i.e., the mass was forced to that of the K^+.

The mass of the X^- was next computed as a missing mass. The mass resolution varied with the mass of X^- and at several typical masses was as summarized in Table I.

Figure 4(a) shows the acceptance of the equipment as a function of the mass of X^-. Figures 4(b) and 4(c) show the missing-mass distributions for K_A and K_B, respectively. Since the missing-mass acceptances and resolutions for the two detectors were different, the missing-mass distributions were not combined. The curves are fits to the mass distributions with χ^2 per degree of freedom of 1.12 and 1.16 for K_A and K_B, respectively.

No statistically significant narrow peaks were observed in either X^- mass distribution. Using the resolution of the equipment, upper limits on the cross section were computed for 95% confidence level. The results are summarized in Table I. An overall upper limit of 4 μb covers the whole mass spectrum from 1.1 to 2.75 GeV/c^2.

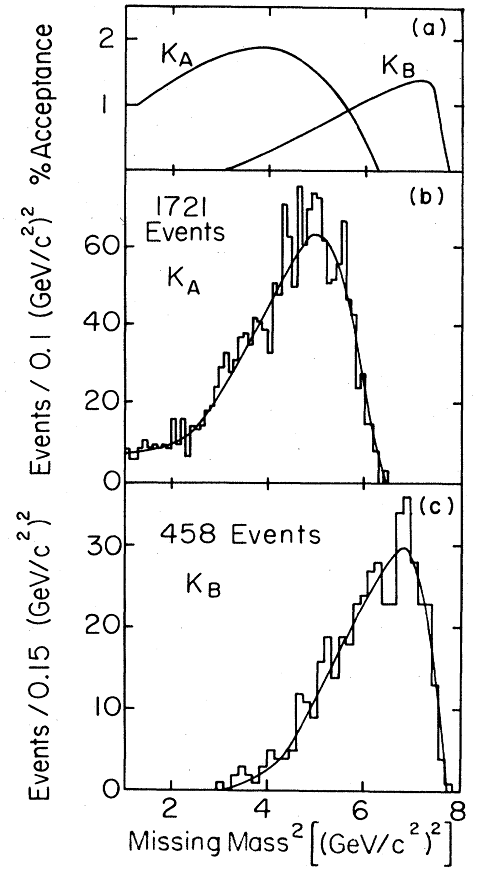

FIG. 4. Missing mass squared (X) for $\bar{p}+p \rightarrow K^+ + X^-$. (a) Acceptance. (b) K_A. (c) K_B. Smooth curves in (b) and (c) are fits to the mass histograms.

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