Search for the H Dibaryon in (K^-,K^+) Reactions

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We have studied (K^-,K^+) reactions from an emulsion target. The $S=-2$ H dibaryon has been searched for by the analysis of the K^+ momentum spectrum together with emulsion data. No evidence of H production was observed in the mass range of 1.90–2.16 GeV/c^2. Upper limits for the production cross section of the H are (0.2–0.6)% of that for the quasifree Ξ^- production at the 90% confidence level.

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The H is an $S=-2$ dibaryon which was first predicted by Jaffe in 1977.[1] Since then the H mass has been calculated in various models,[2] and it ranges from 2.10 GeV/c^2 to around 2Λ mass. Recently, the possibility of a light H (below twice the nucleon mass) has been suggested by lattice QCD calculation.[3] Moreover, the H attracts much attention from the astrophysical viewpoint in relation with strange-quark matter.[4,5] The experimental search for the H in a wide mass range is clearly very important. The purpose of the present work is to search for the H in the mass range of $1.90 \leq M_H \leq 2.16$ GeV/c^2.

Recently, the observation of a weak decay of the H (produced in p-C reaction) in a propane bubble chamber has been reported.[6] However, the associated two kaons (K^+ and/or K^0) were not identified. At BNL, the H in the mass range of 2.0–2.5 GeV/c^2 has been searched for in the reaction $p+p \rightarrow K^+ + K^+ + H$.[7] The upper limits for the production cross section are too large to rule out its existence. From the double weak decay rates of nuclei, the H with $M_H < 1875.1$ MeV/c^2 has been excluded.[8] As for double-Λ hypernuclei, two candidates of their weak decay in emulsion have been reported.[9,10] This may restrict the mass range to $M_H \gtrsim 2.22$ GeV/c^2 or $M_H \lesssim 1.90$ GeV/c^2,[11] although the interpretation of the data is not quite settled.

An emulsion-counter hybrid experiment (E176) has been performed at the KEK Proton Synchrotron using a 1.66-GeV/c K^- beam. The (K^-,K^+) reaction is identified by the counter system. The H can be directly produced from the reaction $K^- + (pp) \rightarrow H + K^+$, where (pp) is a pair of protons in a nucleus.[12,13] If the mass of the H is sufficiently light, the outgoing K^+ has higher momentum than that of the K^+ from the quasifree Ξ^- production process $K^- + (p) \rightarrow \Xi^- + K^+$. The H can be identified by a distinct peak in the K^+ momentum spectrum. By tracing back the K^+ track in the emulsion we can study the event in detail. Independent of the decay mode of the H, this method has the advantage of being sensitive to the H in a wide mass range except near the 2Λ threshold.

The experimental setup is shown in Fig. 1. The typical K^-/π^- ratio of the beam is 1/3 at the intensity of 3×10^3 K^-/spill. The incident K^- are identified with an aerogel Čerenkov counter (AČ1). Its index is 1.04 and the rejection efficiency for the 1.66-GeV/c π^- is 99.3%. Combined with time-of-flight information (T2-T1), π^- contamination in the K^- beam is reduced to less than 10^{-6}. Since the total reaction cross sections for $p(\pi^-,K^+)\Sigma^-$ and $p(K^-,K^+)\Xi^-$ are the same order of magnitude, the background events caused by mistaking π^- for K^- are negligible. For the target, thirteen modules containing a total of 30 liters of nuclear emulsion have been used. Each module consists of 43 sheets (1100 μm thick, 23 cm $\times$ 23 cm in size).[14] The module is held perpendicular to the beam. In order to find the (K^-,K^+) vertex in the emulsion, the K^+ track should be measured with very high precision. For this purpose, the emulsion is sandwiched between 42-μm pitch silicon-strip detectors (BSSD's and VSSD's).[15] We found the K^+ tracks on the last sheet of the emulsion within ~100 μm of the predicted point in most events. The scattered K^+ from the target are detected by a K^+ spectrometer which consists of a magnet (0.7 Tm) multiwire proportional chambers (PC's), drift chambers (DC's), VSSD's, trigger and time-of-flight (TOF) counters, and an aerogel Čerenkov counter (AČ2). Its acceptance is about 0.15 sr and almost constant in a momentum range of 0.9-1.6 GeV/c. The momentum is determined by a spline-fitting method.[16] The resolution $\Delta p/p$ is about 2.5% (rms) at 1.0 GeV/c. It is limited by multiple scattering in AČ2, which is used for rejecting pions (index of AČ2 = 1.06). The velocity is calculated from the track length and the time of flight between the $T2$ and the TOF hodoscope [$\Delta t = 90$ psec (rms)]. The TOF hodoscope is also used as a two-dimensional tracking device [$\Delta y = 12$ mm (rms)]. Finally, we reconstruct the mass of a particle from its velocity and momentum.

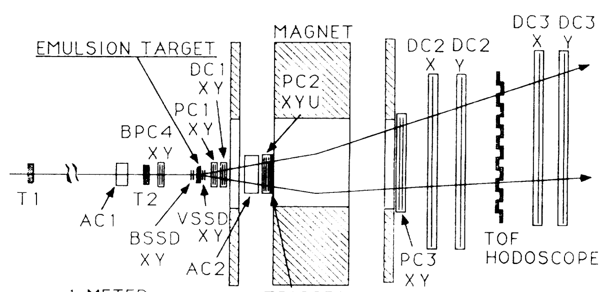

FIG. 1. Schematic view of the experimental setup.

The details of the experimental setup will be reported elsewhere.[17,18]

The obtained mass spectra are shown in Figs. 2(a)-2(c). The resolution for K^+ with $0.9 \le P_{K^+} \le 1.2$ GeV/c is 28 MeV/c^2. It is consistent with the momentum and TOF resolution mentioned above. We estimated the number of misidentified protons (with a measured mass ≤ 0.6 GeV/c^2) as K^+ by fitting the tail of the proton peak with an exponential curve. The expected number in the momentum range of 0.9-1.2 GeV/c is 6.7 and it is 0.4% of K^+ in the same momentum range. It should be noted that more than 98% of π^+ events are already reduced by using AČ2 information. The K^+ momentum spectrum is shown in Fig. 2(d). It is obtained by selecting the events in the mass range of 0.4-0.6 GeV/c^2. K^+ due to quasifree Ξ^- production makes a peak at ~1.1 GeV/c. The number of events from the quasifree Ξ^- process was estimated to be about 1700 by fitting the peak with the result of a Monte Carlo simulation. On the assumption that the angular distribution of K^+ from the quasifree Ξ^- reactions is flat in our acceptance, the laboratory cross section for the emulsion target was calculated to be 96 μb/sr.[19] With the use of information of the target-mass-number dependence of the (K^-,K^+) reaction,[20] the cross section for $K^-p \rightarrow K^+\Xi^-$ was reduced to ~35 μb/sr, which is consistent with previous measurements.[21] No distinct peaks from direct H production are observed in the spectrum.

Without an AČ2 veto, the number of events in the mass range of 0.4-0.6 GeV/c^2 and in the momentum range of 1.3-1.6 GeV/c is 19. Since the π^+ detection efficiency of AČ2 in this momentum region is 98.8%, the expected number of background events due to π^+ mis-

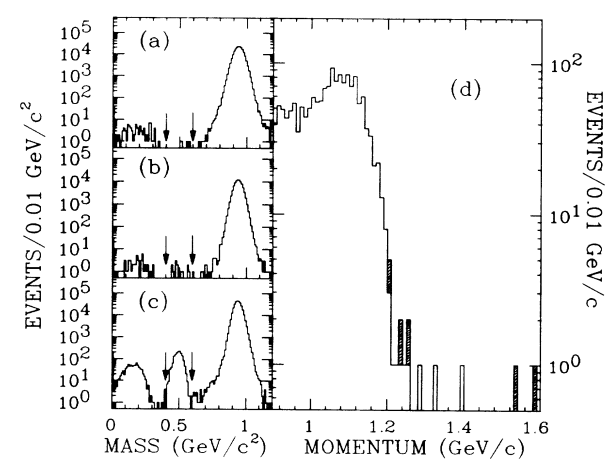

FIG. 2. (a) Mass distribution of scattered particles in the momentum range of 1.3-1.6 GeV/c. The arrows indicate the position of the cuts for selecting K^+. (b) The same as (a) in the range of 1.2-1.3 GeV/c. (c) The same as (a) in the range of 0.9-1.2 GeV/c. (d) Momentum distribution of K^+. The slashed boxes are the events which are rejected by the emulsion analysis.

identification is 0.23 at most. Therefore, as for the light H ($P_{K^+} > 1.3$ GeV/c), the main sources of the background are misidentification of protons as K^+ and the decay of scattered K^-. We reduced these background events by tightening χ^2 cut on the tracks and by cutting events with small scattering angles (≤ 60 mrad).

These procedures also cut K^+ events down to 85%. It was confirmed that these cuts have no momentum dependence above 0.9 GeV/c by comparing two momentum distributions of protons before and after the cuts. There are four events above 1.3 GeV/c which are consistent with the tail of the proton peak in the mass spectrum. We have studied the vertices of these four events in the emulsion and two of them were shown to be due to background reactions using information from the emulsion stack. In one of those two events ($P_{K^+} = 1.58$ GeV/c), two charged particles were emitted from the reaction vertex. Their total energy (kinetic and binding energy) has been estimated to be more than 120 MeV from their track lengths.[22] Therefore, kinematically, this event could not be caused by the direct production of the H unless it is extremely light (below $2M_N$). In the other event ($P_{K^+} = 1.53$ GeV/c), a meson (π or K) was emitted from the vertex. Since the mass of the H corresponding to this K^+ momentum is estimated to be ~ 1.95 GeV/c^2 and it is below both the ΛN and the $NN\pi$ thresholds, this event is most likely caused by a misidentified proton, $K^- + A \rightarrow p(\sim 1.5\ \mathrm{GeV}/c) + K^-(\text{or } \pi^-) + X$. As to the other two background events, one ($P_{K^+} = 1.40$ GeV/c) could not be located because its reaction point is at the edge of the emulsion. And the other event ($P_{K^+} = 1.32$ GeV/c) had no extra charged-particle emission at the vertex, which is a candidate for a long-lived H. However, we cannot exclude the possibility that the event was caused by other reactions, decay of a K^- after an elastic scattering in emulsion, rescatterings of a proton or a K^+ in AČ2, and so on.

As for the heavy H, the background comes mainly from the high-momentum tail of the peak due to the quasifree Ξ^- production. By analyzing twelve events with $1.2 \leq P_{K^+} \leq 1.3$ GeV/c in the emulsion, we found four events in which Ξ^- had escaped from the target nuclei. They have been excluded from the H candidates. The rest of the events were considered to be the background in the calculation of the upper limits for H production. The upper limits for the ratio of the direct H production cross section to that of the quasifree Ξ^- production are shown in Fig. 3. The momentum dependence of the K^+ detection efficiency due to the AČ2 veto, K^+ decay, and the mass resolution have been considered in the calculation.[23] The width of the direct H production peak was assumed to be 100 MeV/c, considering the excitation of a residual nucleus and the momentum resolution. In the mass range of 1.90–2.16 GeV/c^2, the upper limits are (0.2–0.6)%. Theoretically, in Ref. 12, the cross section of H production in ^{3}He(K^-,K^+)nH is calculated. For $m_H = 2.1$ GeV/c^2 and $P_{K^-} = 1.8$ GeV/c, the cross section is about 0.5 μb/sr, which increases monotonously as m_H decreases. Since the cross section is proportional to the elementary cross section, $K^- p \rightarrow K^+ \Xi^-$, the ratio of the cross section for H production to that for quasifree Ξ^- production at 1.66 GeV/c is expected to be same as that at 1.8 GeV/c. In the mass range of 1.90–2.16 GeV/c^2, the ratio is about (0.6–0.4)%, which is same order of magnitude as those of upper limits obtained here. To exclude the possibility of the H in this mass range, however, we have to await reliable estimates of the H production cross sections in complex nuclei.

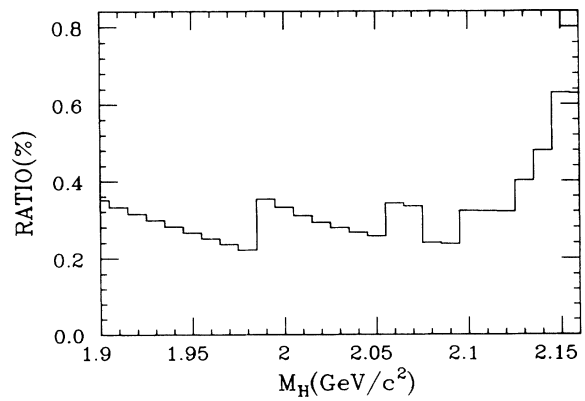

FIG. 3. The ratio of the direct H production cross section to that of the quasifree Ξ^- production for the emulsion target. The line corresponds to the obtained upper limits at the 90% confidence level. The calculation was done at every 10-MeV/c^2 step assuming that the width of H production is 100 MeV/c.

In summary, we have searched for the H by the analysis of the K^+ momentum spectrum in the (K^-, K^+) reaction together with information of the reaction vertices in the emulsion. Upper limits for the production cross section of the H in the mass range $1.90 \leq M_H \leq 2.16$ GeV/c^2 are (0.2–0.6)% of the quasifree Ξ^- production at the 90% confidence level.

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