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SEARCH FOR THE H-DIBARYON AT THE BROOKHAVEN 2 GeV/c KAON BEAM LINE

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In this talk I will summarize the motivation for H-dibaryon searches and describe efforts at Brookhaven to find this particle. The most recently run experiment, using a new 2 GeV/c kaon beam line, has looked for the H in the at-rest formation reaction $(\Xi^- + d)_{atom} \rightarrow H + n$, where the monoenergetic neutron was detected. This experiment is sensitive to an H in the range near the ΛΛ mass, a region largely unconstrained by other measurements. Data analysis is in progress, so no results are available yet. A second search technique using a ^{3}He target is also described.

INTRODUCTION

The H-particle is an S=–2 dibaryon containing the quark flavors (uuddss) coupled to spin zero, isospin zero, and positive parity. It was first discussed by Jaffe[1] in the context of the MIT bag model, who found that this particularly symmetric six quark configuration also has the largest attractive color-magnetic interaction. The S-wave overlap of the quark spatial wavefunctions makes the H qualitatively different from a deuteron-like state of two baryons such as a ΛΛ pair. The color hyperfine splitting which describes the spin-spin interaction between quarks due to one-gluon exchange is of the form [2]

$$H_{hfs} \propto -\sum_{i>j} \frac{(\lambda_i \cdot \lambda_j)(\sigma_i \cdot \sigma_j)}{m_i m_j}$$

where the σ_i and λ_i are the Pauli and Gell-Mann matrices, respectively, and the sum is taken over all quark pairs. In the SU(3) flavor symmetric limit the expectation values of this interaction for the **490**, **189**, and **1** representations of color-spin SU(6) are proportional to –24, +8, and +48, respectively, where the first case has the greatest attraction. Among the possible six quark wavefunctions, the H is a member of the **490** representation of color-spin SU(6), and a singlet in flavor SU(3). In static quark models of the baryons, H_{hfs} produces the 300 MeV mass splitting between the proton and the Δ(1232), for example. In the SU(3) flavor limit it leads to a H binding energy of B_H=150 MeV relative to the two-lambda mass, $2m_\Lambda$, and B_H=53 MeV when quark mass splitting is turned on[2]. These values can be compared to the first bag model prediction for the H mass of 2150 MeV, corresponding to binding B_H=80 MeV [1].

Figure 1 shows the experimental and theoretical situation today, though I have not attempted to show all mass predictions made to date. Jaffe used a static bag for his estimates of the H mass. Liu and Wong [3] removed the spurious center-of-mass motion in the static bag model, and found that the H mass increased enough to un-bind it by B_H=–10 MeV. Other bag model predictions include Aerts, Mulders and deSwart[4], who found B_H=+31 MeV, while Mulders and Thomas [5] found B_H=+10 MeV in a model that introduced a pion field around the bag. In the non-relativistic quark cluster model of Straub *et al*[6], both one-gluon exchange and meson exchange potentials were used in a fit to the baryon octet masses and hyperon-nucleon scattering data; the model resulted in an H bound by 15 MeV. A similar calculation by Oka, Shimuzu and Yazaki [7] which did not use the long-range meson exchange terms used in Ref 6] yielded an H unbound by 26 MeV.

Lattice gauge calculations have yielded conflicting results. Mackenzie and Thacker[8] found that the H should be unbound when using a $(6^2 \times 12 \times 18)$ lattice, but later a similar calculation by Iwasaki, Yoshie and Tsuboi [9] on a $(16^3 \times 48)$ lattice produced an H so light that it was actually below the two-nucleon mass. Nuclei might then possibly decay into strange matter. An H this light has been excluded by Ejiri *et al* [10] who compared their predicted rates of H production in a variety of double weak decay processes with data. A lower limit on the H mass very close to the deuteron mass was obtained.

Various experimental searches for the H have been done. Carroll *et al* [11] set an upper limit of 40nb on H production (for m_H below $2m_\Lambda$) in the reaction $p + p \to H + K^+ + K^+$ at 5.4 GeV/c. Theory predicts a production rate of about 1 nb in this channel, however. Shabahzian *et al* [12] report two separate events from propane bubble chamber data which they interpret as H formation, but which lead to two statistically different mass values, as show in Figure 1. Aoki *et al* [13] have looked for H formation in emulsion nuclei in the reaction $K^- + (pp)_{bound} \to K^+ + H$, where the K^+ momentum spectrum was analyzed above the quasi-free Ξ production region. For an H mass between 1.90 and 2.16 MeV/c^2 they set an upper limit on H production of about 0.6% of quasi-free cascade production.

Indirect limits on the mass of the H come from searches for double lambda hypernuclei. Three events have been reported [14],[15] in emulsion data which have been claimed to show the formation of hyperfragments containing two bound lambdas, followed by their sequential weak decay by mesonic and non-mesonic decay channels. If the m_H is lighter than $2m_\Lambda - B_{\Lambda\Lambda}$, where $B_{\Lambda\Lambda}$ is the binding energy of the two lambdas in the nucleus, then the lambdas will decay strongly into the H inside the nucleus. Assuming that such an H is not bound to the nucleus and/or is long-lived enough to escape detection via decay topologies similar to 2 lambda decays, then the observation of sequential weak decays places a lower limit on the H mass of $2m_\Lambda - B_{\Lambda\Lambda}$ (for zero H binding). The most recent of these results [15] is discussed in these proceedings by Professor Imai [16]; the lower limit so placed in their interpretation [15] is $m_H > 2214.6 \pm 0.7$ MeV/c^2, which corresponds to H binding of 16.7 MeV or less.

In summary, the H is a special object predicted in many models of non-perturbative QCD. It is unique in that it may be bound against strong decay, and hence appear as a narrow, long-lived state. The experimental evidence is so far inconclusive because no one has yet achieved the necessary sensitivity or been able to cover the full mass range to locate the H.

EXPERIMENTS AT THE AGS

Two experiments [17] are underway at the Brookhaven National Laboratory AGS to look for the formation of the H particle and to determine its mass. Both experiments use the same apparatus to deposit 2 units of strangeness in their respective targets using the (K^-, K^+) reaction. Figure 2 shows the concepts of the two experiments. In the two-target configuration, first run in 1991 (E813), a free Ξ^- particle is produced in a hydrogen target and brought to rest in a deuterium target where a Ξ^-d atom is formed. In the one-target configuration using ^{3}He (E836), to be run in two years, the Ξ^- is a virtual particle within the nucleus.

The two-target experiment uses the at-rest reaction $(\Xi^- + d)_{atom} \rightarrow H + n$, where the monoenergetic neutron is detected and determines m_H or B_H directly from two-body kinematics. How this is arranged is shown schematically in Figure 3. The 1.7 GeV/c K^- beam was produced by the newly-commissioned 2 GeV/c beam line at the AGS. It has two independent stages of electrostatic K/π separation, is corrected to third order in its optics, and has achieved a 3.5:1 π/K ratio with a flux of 0.6×10^6 K^-/sec for an AGS primary beam intensity of 10^{13} protons/spill. Drift chambers and two aerogel Cerenkov counters (n=1.03) track and identify kaons in the beam line. Time of flight over 18 meters between hodoscopes in the beam line is used to further select the kaons.

The "bottom" target contains 60 cm of liquid hydrogen, from which the outgoing K^+ mesons emerge at about -9^o. These kaons are momentum analyzed by tracking through a large aperture dipole magnet; the expected resolution of the tracking system is $\delta p/p = 0.5\%$. Particle identification is done using two aerogel Cerenkov detectors (n=1.04) for π/K separation, a Lucite Cerenkov detector for on-line p/K separation, and time-of-flight over a seven meter flight path from the target to the last scintillator hodoscope. The principle background at the first trigger level is due to a roughly 200:1 ratio of elastic and inelastically scattered protons to K^+s. In the off-line analysis the principle background will be due to misidentified pions from Σ production reactions.

Ξ^- particles emerge from the hydrogen target at about $+18^o$ with a kinetic energy of 121 MeV. They pass through a tungsten energy degrader followed by a layer of silicon detectors of a combined thickness selected to maximize the stopping probability of the Ξ^- particles in the liquid deuterium. The diffused junction silicon detectors are arranged in rows of 1cm^2 pads, and are used to signal (redundantly) the creation of the Ξ^- particles and indicate that the particles have survived almost to their stopping points in deuterium. These 200 μm thick detectors absorb between 1.3 to 3 MeV of energy from the slow Ξ^- particles, which is easily seen using preamps located outside the vacuum housing; the detectors themselves operate close to liquid hydrogen temperature (18 K) in the vacuum between the halves of the target.

Once in the deuterium, the Ξ^- particles are captured by molecular and Auger processes into atomic orbits on a time scale comparable to the weak decay time scale of the Ξ^- [18]. Stark mixing is expected to quickly populate S-state levels with high principle quantum number. We expect 1% of all K^+ triggers to be events in which the Ξ^- survives long enough to form an atom in such a state. Once formed, the atom it is expected to decay by the strong interaction to either $\Lambda\Lambda n$, Ξnn, or Hn final states. Aerts and Dover have calculated [18] the branching ratio for H formation:

$$R = \Gamma((\Xi^- + d)_{atom} \rightarrow H + n)/\Gamma((\Xi^- + d)_{atom} \rightarrow \text{anything})$$

and have shown that it is near 1.0 when m_H is close to $2m_\Lambda$, i.e. with small binding, and near 0.1 if the H is bound by as much as 100 MeV. The experiment is sensitive to branching ratios as low as a few percent. The predicted ratios assume that the D version of the Nijmegan hyperon-nucleon model applies in the low energy hyperon-nucleon regime. Even if the H is unbound by up to 15 MeV we expect still to be able to detect the associated neutron. The experiment is thus sensitive to an H mass for the binding energy range 100 MeV > B_H>–15 MeV.

Neutrons are detected in an array of 100 scintillator bars which have a solid angle coverage and detection efficiency product of about 0.10 for the neutron energies of interest. Measurement of neutron time of flight over about one meter will determine the energy of the neutrons and hence the mass of the H.

In estimating the total H formation detection rate, we take into account the K^+ trigger rate, the atom formation rate, the neutron detector efficiency, etc, and find an expected rate of 0.35R per hour, where R is the branching ratio mentioned above. In the running of E813 in 1991, we estimate the number of recorded H events to be about 20R. These are currently being analyzed. We expect to have a "production" run of this experiment in 1992 which should reach a total of about 630R events.

Complimentary to the experiment discussed above is a future measurement using the ^3He target reaction (E836), as was shown in Figure 2. It has been shown [5] that detection of the K^+ is sufficiently defined kinematically to see a narrow bump in the K^+ momentum spectrum to indicate H formation. The centroid of the three-body peak defines the H mass. Despite the intermediate Ξ being far off shell (≈400 MeV/c), the fact that both steps of the reaction happen in one nucleus makes the count rates in this experiment competitive with the two-target experiment. Because of a large background of quasi-free Ξ production, this reaction is not sensitive to H formation for H masses larger than about 2200 MeV (30 MeV binding), but it is sensitive to more deeply bound H particles than the previous experiment. The two measurements are viewed as complimentary in this sense.

The principle backgrounds in the ^3He experiment are from misidentified final state pions from Σ and Y^* production, which are expected to be produced at rates up to 3 orders of magnitude larger than K^+ from H formation. Similarly large backgrounds occur if incident pions are misidentified as kaons. Particle identification at the $1{:}10^4$ level is therefore crucial for this version of the H search. Since both incoming and outgoing arms of the experiment have three separate particle identification methods (two threshold Cerenkovs and time-of-flight), the collaboration believes it will reach the necessary level of pion rejection.

In summary, the H particle has a special place in models of nonperturbative states of six quarks, in that it is expected to have the most attractive hyperfine interaction, and therefore may be stable against strong decay. Many models have made predictions for its binding energy relative to $2m_\Lambda$, either positive or negative, and experimental verification is now fairly close. Two direct searches at Brookhaven are now underway, with one experiment having run for the first time in 1991. However, it is still somewhat too early to have results.

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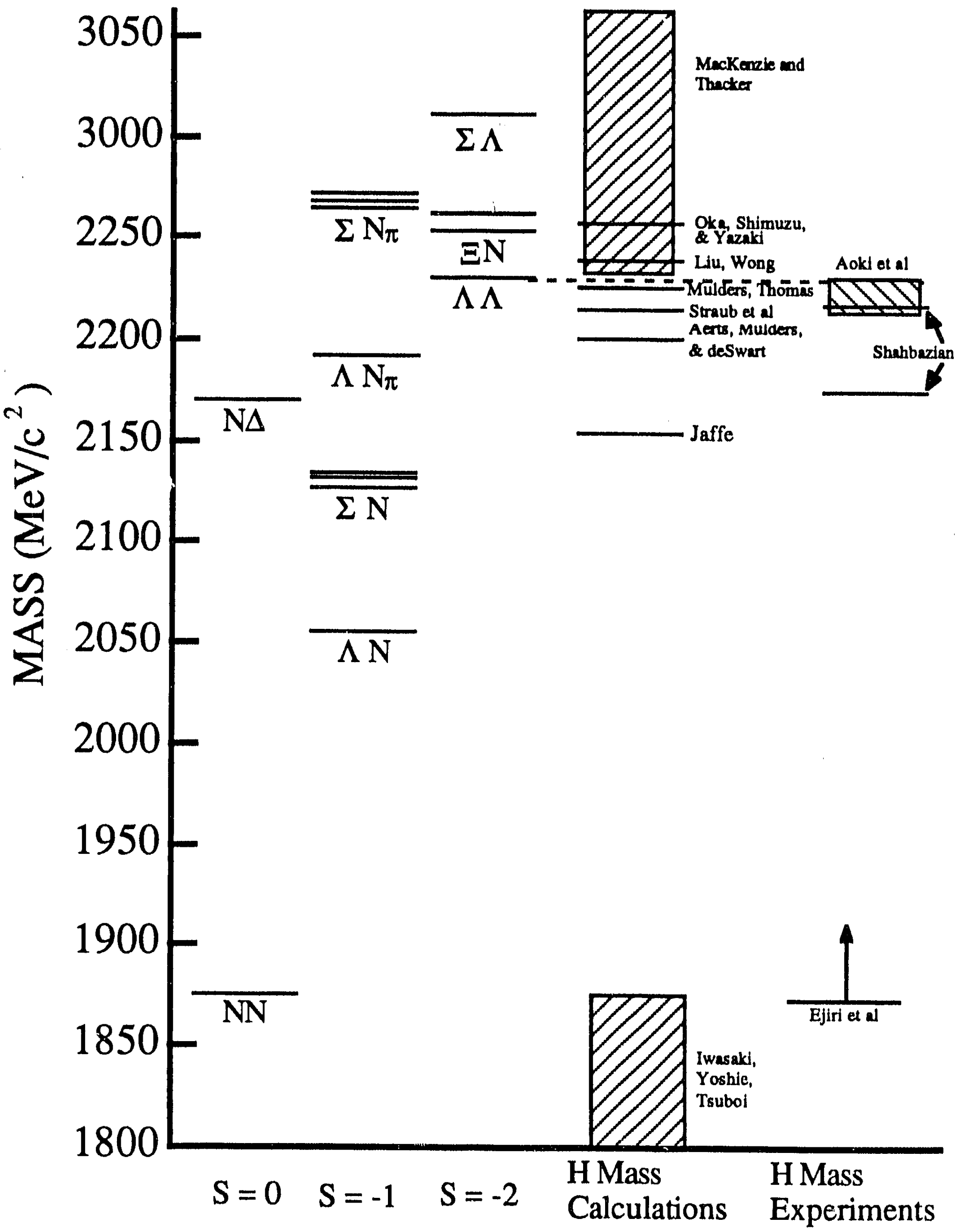

Figure 1) Mass scale for two-baryon systems, with theoretical predictions and experimental limits for the mass of the H particle. See text for references.

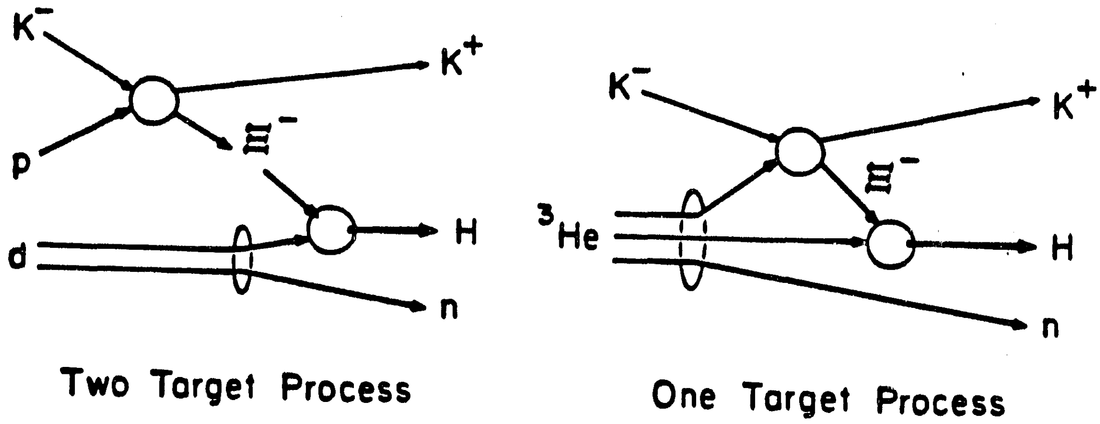

Figure 2) The reaction steps leading to H formation in the dual H_2/D_2 target setup and the single ^3He target setup. In either case the K^+ is detected, while in the first case the neutron and Ξ^- are also detected.

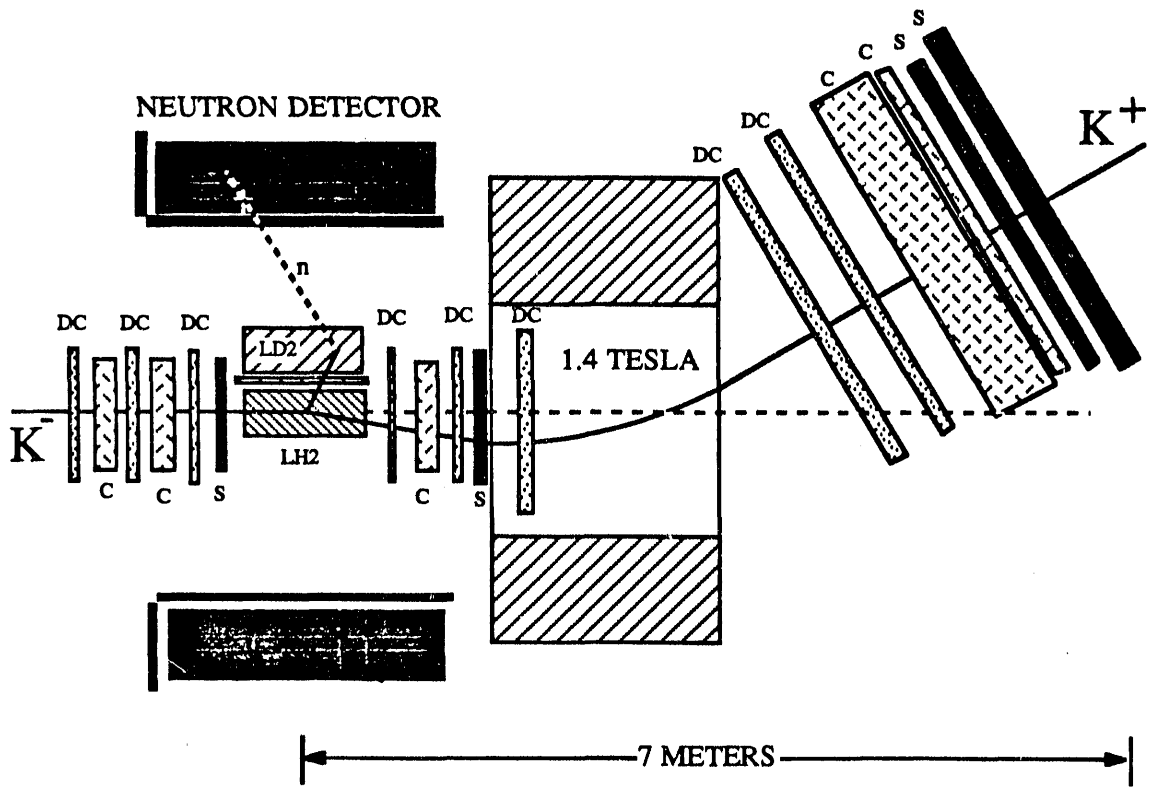

Figure 3) Schematic layout (not to scale) of Experiment 813, the H search. DC = drift chamber, C = Cerenkov detector, S = scintilla or hodoscope. The drawing is an elevation view except for the neutron detectors which are actually placed horizontally on either side of the target. The unscattered beam (not shown) is bent downward away from the downstream detectors.

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