SEARCH FOR THE WEAK DECAY OF AN H DIBARYON

B. WARE [a]
The University of Texas at Austin,
Austin, Texas 78712 [b]

We have searched for a neutral H dibaryon decaying via $H \to \Lambda n$ and $H \to \Sigma^0 n$. Our search has yielded two candidate events from which we set an upper limit on the H production cross section.

QCD imposes no inherent limitation on the number of quarks composing hadrons other than that they form color singlet states. Although only qqq and $q\bar{q}$ states have been observed, other combinations can form color singlets. Jaffe[1] proposed that a six-quark state $uuddss$ may have sufficient color-magnetic binding to be stable against strong decay. Such a state, which Jaffe named H, would decay weakly, and the resultant long lifetime would allow the possibility of observing such particles in neutral beams. Theoretical estimates of m_H have varied widely, ranging from a deeply bound state with $m_H < 2.10$ GeV$/c^2$ to a slightly unbound state with m_H near the $\Lambda\Lambda$ threshold, 2.23 GeV$/c^2$. In this mass range the H would decay almost exclusively to Λn, $\Sigma^0 n$, and $\Sigma^- p$.[2] Several previous experiments have searched for H's with no compelling success.[3]

We have searched for $H \to \Lambda n$ and $H \to \Sigma^0 n \to \Lambda \gamma n$ decays by looking in a neutral beam for $\Lambda \to p\pi^-$ decays in which the Λ momentum vector does not point back to the production target. A second phase of this experiment searched for long-lived H's by using a diffractive dissociation technique.[4] The detector used for the decay search was essentially that used for the E791 rare kaon decay experiment and has been described in detail elsewhere.[5,6]

The primary backgrounds to this experiment were kaons produced in the target and lambdas produced by secondary neutral interactions downstream of the target. To reject background from $K_L^0 \to \pi^0\pi^+\pi^-$, we required $m_{\pi^+\pi^-} > (m_{K_L} - m_{\pi^0})$; to reject background from $K_S^0 \to \pi^+\pi^-$ resulting from secondary interactions, we required $|m_{\pi^+\pi^-} - m_{K_L}| > 4$ times the mass resolution of $K_L^0 \to \pi^+\pi^-$ decays (1.55 MeV$/c^2$). Particle identification was used to reject background from $K_L^0 \to \pi e \bar{\nu}$ (K_{e3}) and $K_L^0 \to \pi\mu\bar{\nu}$ ($K_{\mu 3}$) decays.

Lambda candidates were selected by requiring that $|m_{p\pi^-} - m_\Lambda| < 4$ times the mass resolution of $\Lambda \to p\pi^-$ decays (0.55 MeV$/c^2$). The data was then divided into two streams: a normalization stream consisting of Λ's which project

[a] Representing the E888 Collaboration at Brookhaven
[b] Present address: California Institute of Technology, Pasadena CA 91125.

back to the production target, and a signal stream consisting of Λ's which do not. The former were selected by requiring that the square of the collinearity angle θ_Λ be less than 1.5 mrad^2, where θ_Λ is the angle between the reconstructed Λ momentum vector and a line connecting the production target with the decay vertex. The signal sample was selected by requiring that $p_T > 145$ MeV/c, where p_T is the Λ momentum transverse to the line connecting the production target with the decay vertex. This cut value was chosen to eliminate $\Xi^0 \rightarrow \Lambda\pi^0$ decays, which have a kinematic endpoint of 135 MeV/c. The p_T distribution of Λ's from two-body $H \rightarrow \Lambda n$ decays exhibit an approximate Jacobian peak with an endpoint which depends upon m_H. A large fraction of high-p_T Λ's were found to project back to a collimator located just upstream of the decay tank. We thus required that the point in our beamline to which a Λ projects back be located downstream of this collimator: $z_{\rm proj} > 9.65$ m.

A signal region for H candidates was defined by the criteria $p_T > 174$ MeV/c and $N_\tau > 5$, where N_τ is the distance in proper lifetimes between the decay vertex and the nearest beamline element to which the momentum vector projects back. The p_T cut rejects $K_{\ell 3}$ decays which survive particle identification vetoes due to detector inefficiency, while the N_τ cut rejects Λ's which originate from collimators, flanges, and other beamline elements. All cuts were determined without looking at events in the signal region, in order that our final limit on H's be unbiased. After fixing cuts we looked in the signal region and observed two events. The estimated background is 0.15 events from Λ's originating from beamline elements, and fewer than 0.21 events from $K_{\ell 3}$ decays (all K_{e3} as the p_T is too high for $K_{\mu 3}$). The former is estimated by studying the N_τ distribution of Λ's originating from a "hot" flange located upstream; the latter by comparing events cut by electron particle identification in the signal sample to a similar sample of K_{e3} decays from the minimum bias sample. The N_τ vs. p_T plot for the final high-p_T Λ sample is shown in Fig. 1a.

The two candidates have p_T of 187 and 191 MeV/c and N_τ of 6.7 and 9.4. These very similar p_T values correspond to a Jacobian peak from $H \rightarrow \Lambda n$ decay if $m_H \approx 2.09$ GeV/c^2. The probability for a $K_{\mu 3}$ decay to have such high p_T is extremely small, as it is kinematically forbidden for a $K_{\mu 3}$ decay to pass both $m_{\pi\pi} > (m_{K_L} - m_{\pi^0})$ and have $p_T > 160$ MeV/c. The probability for a K_{e3} decay to mimic these events is also very small, as the particle identification response for the candidate tracks is very uncharacteristic of electrons. From a spoiled vacuum data sample, we estimate the background from secondary neutral interations with gas molecules in the vacuum decay region to be 0.04 events. We also studied potential background from $\Xi^0 \rightarrow \Lambda\pi^0$ decays where the Ξ^0 originates from a beamline element and estimate a background of less than 0.10 events. The total background estimate from known sources is less

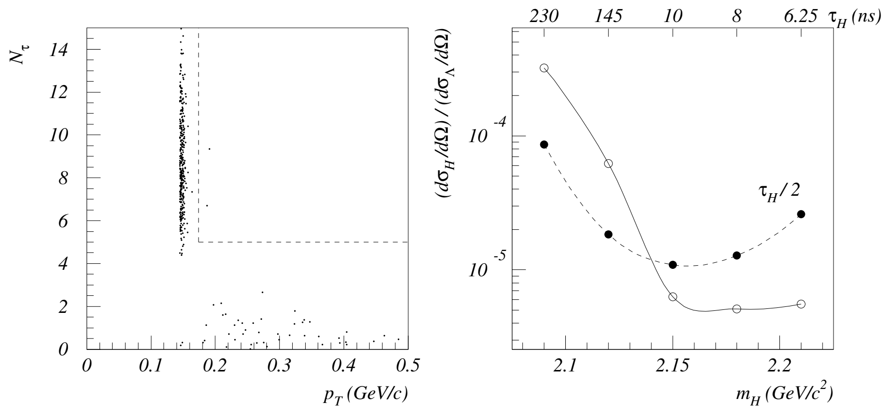

Figure 1: **a.**) N_τ vs. p_T for the high-p_T Λ sample. The signal region is denoted by dashed lines. The band of events from $p_T = 145$ to $p_T \approx 150$ MeV/c are $K_{\mu 3}$ decays; the leftmost edge is due to a p_T cut, while the rightmost edge is due to a lower cut on $m_{\pi\pi}$. **b.**) 90% C.L. upper limits on the H production cross section as a function of m_H or τ_H (see Ref. [2]). The dashed contour corresponds to an H lifetime half that given on the top scale.

than 0.50 events. The probability of 0.50 events fluctuating up to two or more events is 0.090; if such a fluctuation occurred, it is remarkable that the p_T of the events is so similar.

A 90% C.L. upper limit on the H production cross section can be expressed in terms of the inclusive Λ production cross section:

$$\frac{d\sigma_H}{d\Omega} < \frac{\xi}{N_\Lambda^{targ}} \frac{A_\Lambda}{A_H} \frac{B(\Lambda \to p\pi^-)}{B(H \to \Lambda X)} \frac{d\sigma_\Lambda}{d\Omega}, \tag{1}$$

where $N_\Lambda^{targ} = 20\,433$ is the number of Λ's originating from the target, A_Λ and A_H are geometric acceptances for Λ's originating from the target and from H decays, respectively, $B(\Lambda \to p\pi^-)$ and $B(H \to \Lambda X)$ are branching ratios, $d\sigma_\Lambda/d\Omega$ is the inclusive Λ production cross section, and ξ is the factor which multiplies the single-event sensitivity to give the value of $d\sigma_H/d\Omega$ which has a 10% chance of producing ≤ 2 detected events. We conservatively assume no background and take $\xi = 5.32$. Since $\Lambda \to p\pi^-$ decays are common to both signal and normalization channels, all trigger and detection efficiencies divide out of Eq. (1).

The acceptances A_Λ and A_H were determined from Monte Carlo simulation using several estimates of the production momentum spectra. We set a conservative limit resulting from a central production spectrum. The inclusive Λ production spectrum was taken from a measurement by Abe *et al.* [7]; comparison with our data shows very good agreement.

The acceptance A_H also depends crucially on H lifetime. Here we assume the relationship between m_H and τ_H, $B(H \to \Sigma^0 n)$, and $B(H \to \Lambda n)$ calculated by Donoghue *et al.*[2] and obtain 90% C.L. upper limits on $(d\sigma_H/d\Omega)\,/\,(d\sigma_\Lambda/d\Omega)$ as a function of m_H. Our limits for $(d\sigma_H/d\Omega)\,/\,(d\sigma_\Lambda/d\Omega)$ are plotted in Fig. 1b. For $m_H \approx 2.15$ GeV/c^2, Jaffe's original prediction,

$$\left.\frac{d\sigma_H}{d\Omega}\right|_{48\text{ mr}} < \left(6.3\times 10^{-6}\right) \left.\frac{d\sigma_\Lambda}{d\Omega}\right|_{48\text{ mr}} \quad (90\%\text{ C.L.}) \tag{2}$$

From Abe *et al.*,[7] $d\sigma_\Lambda/d\Omega|_{48\text{ mr}} = 366$ mb/sr, so $d\sigma_H/d\Omega|_{48\text{ mr}} < 2.3$ μb/sr. For $m_H = 2.09$ GeV/c^2, consistent with the observed Λ p_T, the acceptance is lower and the two candidate events correspond to a differential cross section of $44\,^{+58}_{-28}$ μb/sr. The authors of Ref. [2] note that τ_H may be shorter than their predicted value by up to a factor of two and the resultant 90% C.L. upper limits are plotted as the dashed contour in Fig. 1b. If we assume that the invariant cross section $E\,d^3\sigma/dp^3$ has the form $A(1-|x|)^B e^{-Cp_T^2}$, then our limit (2) gives $\sigma_H < 60$ nb for a wide range of parameters B and C. This is significantly lower than published theoretical predictions.[8]

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