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Search for the H Dibaryon by Ξ^- Capture on the Deuteron

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ABSTRACT

The present status of the H-dibaryon search experiment at Brookhaven (E813) using the formation reaction through Ξ^- atomic capture on the deuteron, $(\Xi^-, d)_{atom} \rightarrow H\,n$, is reported with emphasis placed on the analysis of the data collected with the 1992 slow extracted proton beam run.

The H-dibaryon is a six-quark flavor-singlet state (uuddss) with $I = 0$ and $J^\pi = 0^+$. This object was originally discussed by R.L.Jaffe using the MIT bag model in 1977.[1] The essential ingredient in the calculation was the color magnetic hyperfine interaction which gives this state the largest downward shift in the mass spectrum of six quark states. The mass calculated by Jaffe was 2150 MeV, corresponding to 80 MeV below the two-lambda mass ($2m_\Lambda$) and, therefore, the state was predicted to be stable against strong decay. The mass of the H has been estimated since then in a variety of calculations such as the bag model, the non-relativistic quark model, the Skyrme model and lattice QCD. The predicted mass varies from the two-nucleon mass up to the two-lambda mass and beyond. Several experimental efforts have been made to search for this object. However, no evidence has been found so far.[2–4] The double-lambda hypernucleus events which have been found in nuclear emulsion[5–7] may exclude a deeply bound H, however, they cannot exclude an H with binding

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energy up to a few tens of MeV or an unbound H. Therefore, both theoretical and experimental situations regarding the existence of the H remain unsettled.

Experiment 813 at the Brookhaven AGS, is designed to search for the H-dibaryon in the binding energy region $B_H = +100$ to $-15\,MeV$ by detecting the two successive reactions, $K^- p \rightarrow K^+ \Xi^-$ and $(\Xi^-, d)_{atom} \rightarrow H\,n$. The signature of H production would be the detection of the monoenergetic neutrons resulting from stopping Ξ^-'s in liquid deuterium. According to the calculation made by Aertz and Dover,[8] the branching ratio (R) of the formation reaction, $(\Xi^-, d)_{atom} \rightarrow H\,n$, is nearly 80% for the binding energy B_H close to zero and falls with increasing B_H. The experiment is, therefore, more sensitive for a smaller B_H region. The production running of the experiment started in the AGS's 1992 slow extracted proton beam period. The data collected in the 1992 run have been analyzed and the results are reported here.

The experiment utilizes the newly-built $2\,GeV/c$ separated K^- beam line to deliver $1.8\,GeV/c$ K^- mesons to a liquid hydrogen target. A K^- flux of 2.8×10^6 per 10^{13} primary protons was achieved with a $\pi^-\mu^-e^-/K^-$ ratio of 2.5.[9] In the 1992 run, $2.7 \times 10^{11}\,K^-$ was accumulated on target for the data acquisition. The creation of Ξ^-'s with the $K^- p \rightarrow K^+ \Xi^-$ reaction is measured by a K^+ spectrometer instrumented with drift chambers, Čerenkov counters, a time-of-flight counter and trigger hodoscopes. The spectrometer has a resolution of $\sim 1.0\%$ for the momentum measurement and 110 psec (σ) for the TOF measurement.[10] Consequently, the Ξ^- creation can be clearly identified.

The heart of the experiment is the liquid hydrogen(LH_2)/deuterium(LD_2) double target system shown in fig.1. A Ξ^- is created near the top of the LH_2 vessel, passes through one of the degrader slabs and enters the LD_2 with low enough velocity that it may stop in LD_2. Even with this specialized target, however, the fraction of Ξ^-'s stopping in the LD_2 is very small (less than 1%) and vast majority decay in flight or stop in the degrader. Another important tag comes from the silicon detector pads ($200\,\mu m$ thick) mounted behind each degrader slab to enhance the stopping probability and thus to improve the ratio of monoenergetic neutron signals to background neutrons originating from the Ξ^-decay. Based on our Monte Carlo simulation, events having an energy deposit of $1.0 - 2.0\,MeV$ in one of the silicon pads close to the Ξ^- creation vertex are selected. In fig.2, the fraction of silicon-tagged events is plotted as a function of the outgoing K^+ angle (θ_{K^+}) and compared to the Monte Carlo simulation on an absolute scale. The peak around $\theta_{K^+} = 8°$ is made by the Ξ^-'s whose initial momenta are optimum to give the tag and the tails can be explained by the background hits of protons and pions from the Ξ^- decay chain. The simulation indicates that most of the stopping Ξ^-'s populate the region $\theta_{K^+} = 5° - 9°$ and the stopping probability is $\sim 8.6\,\%$ for the silicon-tagged events in that angular region. The number of tagged events found in the analyzed data is about 1500. Therefore, we estimate about 130 $(\Xi^-, d)_{atoms}$ were formed.

Fig.1 Expanded view of the LH_2/LD_2 target. A Ξ^- stops in the LD_2 between two degrader cells. Twenty cells are positioned every 3cm.

Fig.2 Fraction of silicon tagged events as a function of the K^+ angle. The data (closed circles) are compared to the simulation (open circles).

Neutrons are detected by two arrays of plastic scintillator logs (10 logs $\times$ 5 layers) placed on both sides of the target. Fig.3 shows a preliminary spectrum of the inverse neutron velocity (β^{-1}) associated with the 1500 silicon-tagged events (plotted with error bars). The threshold applied for the light output of a log is $1\,MeV_{ee}$ (electron-equivalent) in the present analysis. In this spectrum, we anticipate a signal of: (number of $(\Xi^-, d)_{atom}$ formed)$\times$ (branching ratio of the formation reaction, $(\Xi^-, d)_{atom} \rightarrow H\,n$)$\times$ (solid angle of the array)$\times$ (neutron detection efficiency) $\sim 130 \times R \times 0.32 \times 0.38 = 15 \times R$. The estimated size of a monoenergetic neutron peak with $R = 1$ is indicated in the figure for several binding energies ($B_H = 50, 20, 0$ and $-10\,MeV$). The width of the peak is estimated based on the TOF resolution which is found to be $\sim 290\,psec(\sigma)$ and also the path length ambiguity, whose effect on the width depends on the neutron velocity. The dotted line gives an estimation for the background which is based on the spectrum of neutron hits associated with ~ 22000 (K^-,K^+) events where the silicon-tag is not required (scaled by the number of events, i.e. scaled by 1500/22000). The nature of the background arises from the neutrons resulting from π^- capture reactions on various materials where the π^-'s originate from the Ξ^- decay chain. The ratio of signal to noise (S/N) depends on B_H and it is found to be , for example, $\sim 0.4 \times R$ at $B_H \sim 0\,MeV$ and $\sim 0.2 \times R$ at $B_H \sim 50\,MeV$. Further studies are being made to find the optimum cuts in the offline analysis to maximize the sensitivity for the signal.

Our goal was to accumulate $10^{12}\,K^-$ on target and this was achieved during the 1993 run. The statistics should then be about four times what is presented here. Fig.4 shows the estimated sensitivity of the experiment with this improved statistics and with the same S/N ratio as found in the present analysis. In the figure, the solid line represents "the lower bound for the branching ratio R giving a $3\,\sigma$ or better signal". Therefore, if the H exists with small binding energy, and the branching ratio is as high as $\sim 80\,\%$ (ref.8), we have a good chance to find the peak in the existing data.

Fig.3 Preliminary neutron β^{-1} spectrum (see text). Scales are given also for the binding energy (B_H) and for the neutron kinetic energy(T_n).

Fig.4 The lower bound of the branching ratio (R) giving a 3σ or better signal (solid line) and the calculated R in ref.8 (dotted line).

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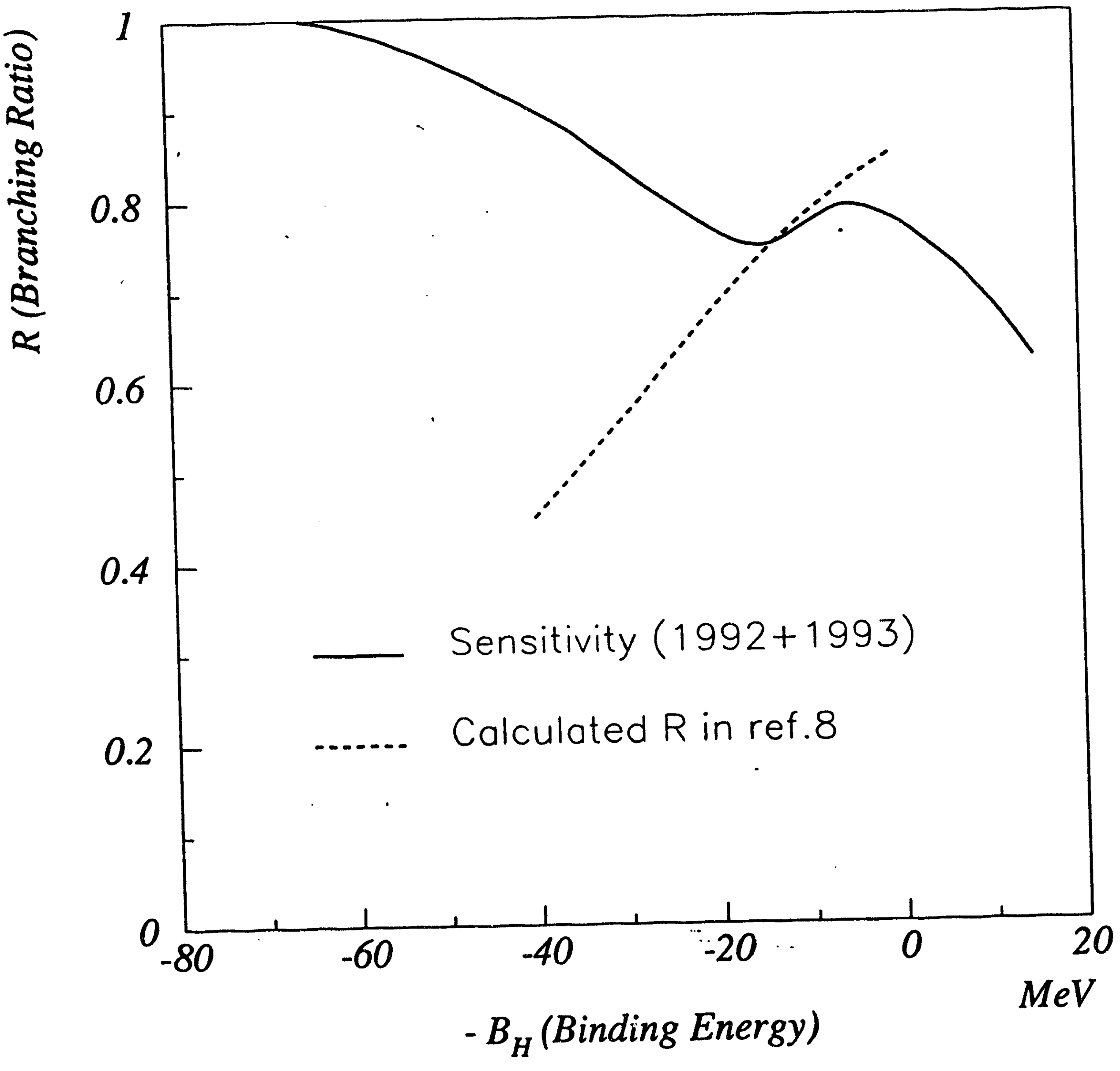
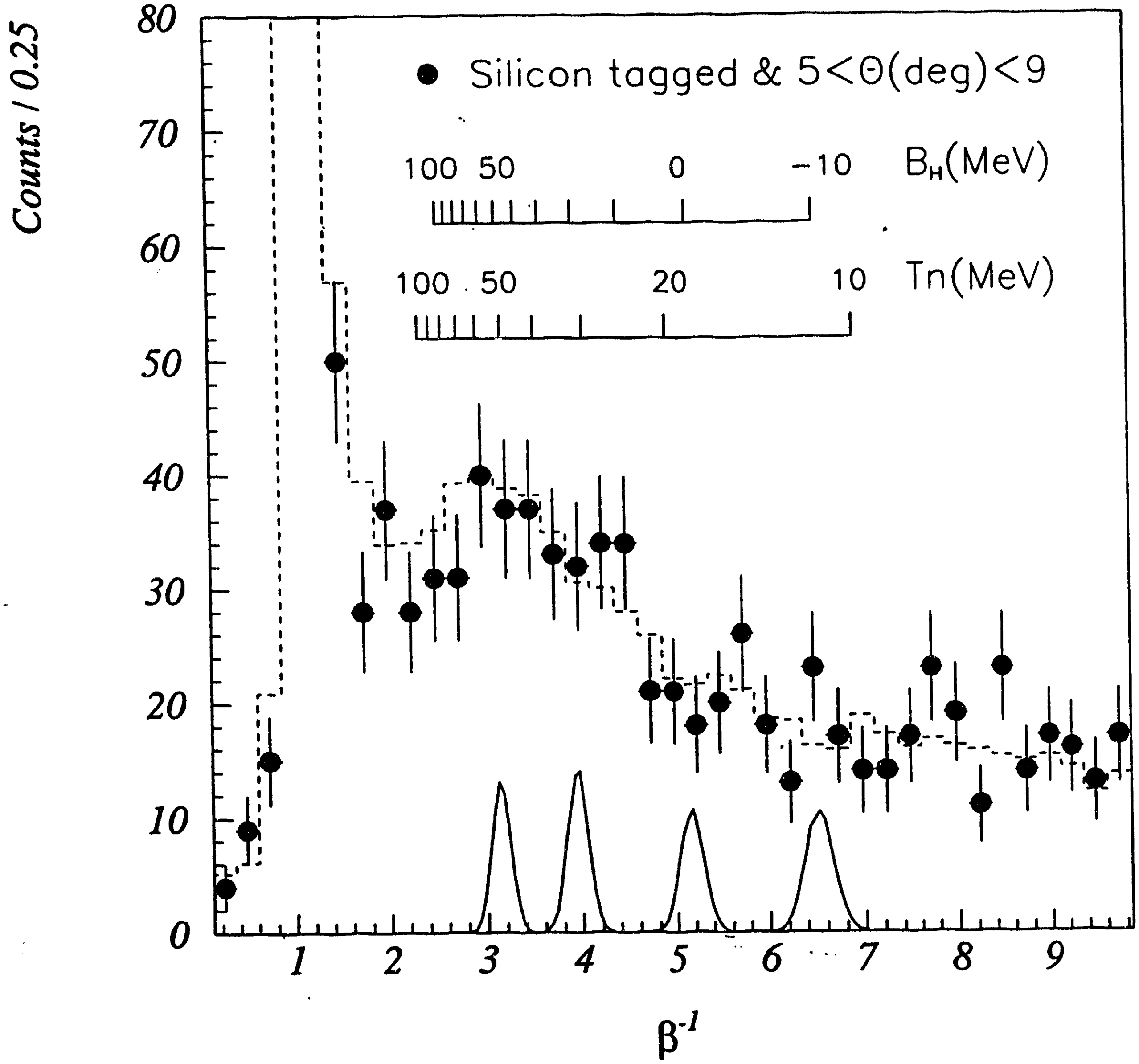
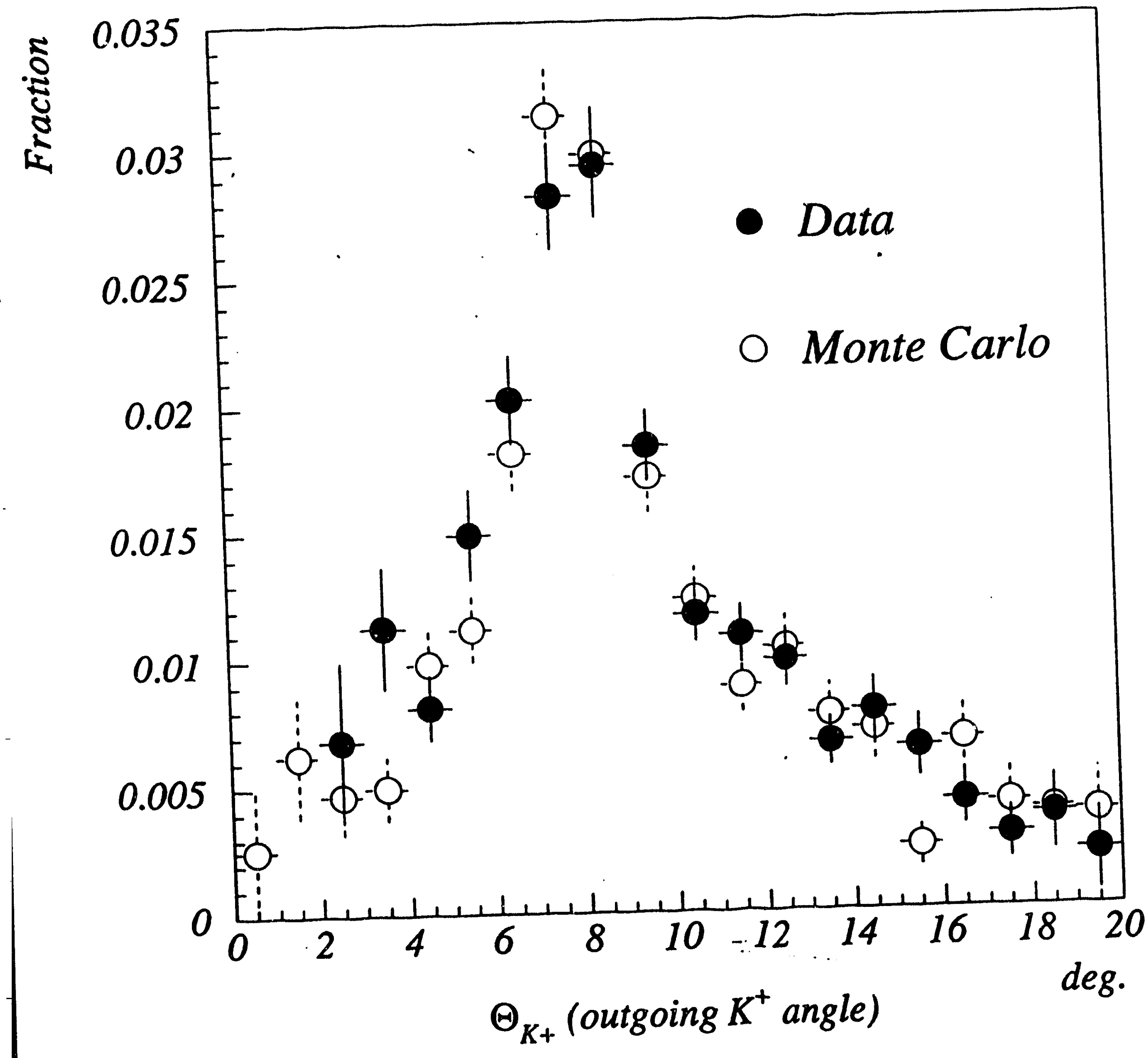


R (Branching Ratio)
1
0.8
0.6
0.4
0.2
0
-80
-60
-40
-20
0
20
MeV
- B_H (Binding Energy)
Sensitivity (1992+1993)
Calculated R in ref.8



Counts / 0.25
Silicon tagged & 5<Θ(deg)<9
100 50 0 −10 B_H(MeV)
100 50 20 10 Tn(MeV)
β^{-1}


Fraction
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
Data
Monte Carlo
0
2
4
6
8
10
12
14
16
18
20
deg.
Θ_{K+} (outgoing K^+ angle)

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