Search for the H-dibaryon

A Proposal to E871

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H-dibaryon: *A long-lived, six-quark particle--2 u's, 2 d's, 2 s's.*
All six quarks are in one 'bag'.

$$\begin{aligned} S &= -2 \\ J^P &= 0^+ \\ I &= 0 \end{aligned}$$

Mass

Jaffe (1977): MIT Bag Model predicts dibaryon state below threshold for strong decay.

$$M_H = 2.150 \text{ GeV}/c^2 < M_{2\Lambda} = 2.231 \text{ GeV}/c^2$$

→ *Maximal Color, Flavor and Spin Symmetry leads to Maximum Color Magnetic Interaction.*

QCD Analog of Magnetic Hyperfine Splitting in Hydrogen

$$\vec{S} \cdot \vec{J}$$

$I = \text{nuclear spin}$

$$\vec{J} = (F+1)$$

$J = \text{electron angular momentum}$

$$\vec{F} = \vec{I} + \vec{J}$$

Same effect as splitting between proton and Δ^{++} masses

$$J_p = 1/2, J_\Delta = 3/2$$

$$|M_p - M_\Delta| = 300 \text{ MeV}$$

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MASTER

Theoretical Mass Estimates vs. Date

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Weak Decay Thresholds -- Donoghue, Golowich, and Holstein.
(1986)

$H \rightarrow nn$ (1.878 GeV/c²)
 $H \rightarrow \Lambda n$ (2.055 GeV/c²)
 $H \rightarrow \Sigma N$ (2.136 GeV/c²)
 $H \rightarrow \Lambda N\pi$ (2.195 GeV/c²)

Above ΣN Threshold $\Delta I=1/2$ Rule Predicts

$$\Sigma^- p : \Sigma^0 n : \Lambda n :: 1 : -\frac{1}{\sqrt{2}} : -\frac{\sqrt{2}}{6}$$

but instead

$$\Sigma^- p : \Sigma^0 n : \Lambda n :: 1 : 1.06 : -.61$$

First Violation of $\Delta I=1/2$ Dominance in Weak Decays.

Physics

1. Low Energy Test of QCD

2. New Form of Matter

3. 'Missing Link' between normal Hadronic Matter and Strange Matter.

Strange Matter: High baryon number clumps of quarks, $\approx 1/3$ strange.

Biorken and McLerran (1979): Metastable strange matter explains Centauro cosmic ray events.

Witten (1984): Strange Matter may be absolutely stable.

Fermi momentum $p_F \sim N^{1/3}$

For 3 flavors then p_F decreases
and average kinetic energy

goes down by $\frac{\langle E_k \rangle_3}{\langle E_k \rangle_2} \approx .89$

$\rightarrow 50-70 \text{ MeV/baryon}$

lower than
normal matter

Normal nuclei remain normal because of long lifetime.

$$\rightarrow G_F^{2A} \text{ For } A \approx 4, \tau > \tau_{\text{universe}}$$

'Neutron Feeding' releases energy.

4. Astrophysical Explanations

Cygnus X-3

Hercules X-1

→ Hadronic signature of showers from point source.

orders of magnitude more μ 's than expected from
 γ - μ

→ Pulsars and neutron stars made of strange quark

matter.

5. Cosmology and Dark Matter

Witten: QCD phase transition in early Universe left over large clumps of Strange Matter.

FIG. 1. Isolated expanding bubbles of low-temperature phase in the high-temperature phase.

FIG. 2. The expanding bubbles meet.

FIG. 3. Isolated shrinking bubbles of the high-temperature phase.

Experiments

I. Carroll *et al.*, 1978

Used reaction

$$pp \rightarrow K^+ K^+ X \quad \text{at } 5^{-10}/c$$

Limits: 30-130 nb.

→ Badalyan and Simonov (1982): Expect ≈ 1 nb for this reaction.

II. Condo *et al.*, 1984

80,000 $\bar{p}$ annihilations in C, Ti, Ta, Pb

Reaction $\bar{p}(20) \rightarrow 4^0 K K$ has Q similar to

$$p + \bar{p} \rightarrow 4^0 K K \quad (E_{\text{cm}} = 600 \text{ MeV})$$

Limits: For $\tau_H = \tau_A$, rate for $\bar{p}A \rightarrow HX$ is $< 9 \times 10^{-5}$

But rate for $\bar{p}A \rightarrow \pi^0 \pi^0 X$ is $< 4 \times 10^{-5}$

VI. Current BNL Experiment, Barnes *et al.*

Ξ^- capture in deuterium: $(\Xi^-d)\text{atom} \rightarrow H + n$

→ Neutron is monoenergetic.

Branching ratios R for H production from S and P states of the Ξ^-d atom, as a function of m_H . Results for one-boson-exchange models D and F are shown to provide an idea of the theoretical uncertainty, although model D is preferred (see text).

Sensitive only near threshold ($m_H \approx m_{2H}$)
→ High neutron momenta difficult to detect

III. Shahbazian *et al.*, 1984

Creation and subsequent decay in propane bubble chamber

$$\rightarrow M_H = 2.173 \text{ GeV}/c^2$$

Also found evidence for a 'dilambda resonance' H^*

$$M_{H^*} = 2.365 \text{ GeV}/c^2$$

$$\Gamma = .047 \text{ GeV}/c^2$$

$$\text{Jaffe (1977): } M_{H^*} = 2.414 \text{ GeV}/c^2$$

IV. Aoki *et al.*, 1990

K^- incident on emulsion target.

K^+ in this reaction has higher momentum than in

('quasifree' process)

Limits: .2-.6% of quasifree Ξ^- production cross section at 90% confidence level.

→ Not sensitive either to weakly or deeply bound H.

→ Some candidate events indicating long-lived H, but also consistent with background.

V. $\Lambda\Lambda$ Hypernuclei

2 Λ 's inside nucleus should be in 1S_0 state.

→ Correct q. nos. to form H.

Kerbikov (1984):

$$\epsilon_{\Lambda\Lambda}^{\text{He}} \rightarrow H + \alpha$$

$$\chi \ll \chi_w (\sim 10^{-10} \text{ s})$$

unless

$$m_K \sim m_{\Lambda\Lambda} \text{ or } m_H \sim m_{\Lambda\Lambda}$$

Observed Events

$$\approx 2.221$$

Paper	Nucleus	2π decay	Photo	Confirmed Ξ	$\Lambda\Lambda$ interaction
Danysz 1963	$^{10}_{\Lambda\Lambda}\text{Be}$	Yes	Yes	No	Attractive
Prowse 1966	$^6_{\Lambda\Lambda}\text{He}$	Yes	No	No	Attractive
Aoki 1991	$^{10}_{\Lambda\Lambda}\text{Be}$	No	Yes	Yes	Repulsive

Fig.1(a)

Fig.1(c)

Fig.1(b)

Fig.1(d)

Fig.1(f)

Fig.1(e)

Fig.1 : Photographs and schematic drawings of the double hypernucleus. To obtain better position resolution in the vertical direction (focusing direction of a microscope) in the emulsion, a tiny piece of the emulsion involving this vertex ($0.5 \times 0.5 \times 10 \text{ mm}$) was cut out and swollen by water with sugar to the original thickness before the development. It was scanned from four directions under the microscope. (a) A photograph of the event viewed from the vertical direction. (b) A schematic drawing of the event viewed from the vertical direction. (c)~(e) Photographs of the event viewed from the horizontal direction. Track #5 and Track #7 move along the focusing direction and appear in the photograph (c) and (e) respectively. (f) A schematic drawing of the event viewed from the horizontal direction.

Search at E871

→ Long-lived H 's are in K_L beam

→ *Diffraction Dissociation:* $H p \rightarrow \Lambda \Lambda p$, energy of recoil proton deposited in scintillator and used for mass measurement

Need to know: Number of H 's in beam

Cross section for dissociation process

Acceptance

Cross Section

Two Methods

1. Analogous to neutron reaction $n + p \rightarrow \pi^+ p + p$

Fit diffraction with $\rightarrow \frac{d\sigma}{dt} \sim e^{-bt}$

$$t_{min} = \left(\frac{m_p^2 - m_n^2}{2k_n} \right)^2$$

if $n + p \rightarrow \pi^0 + p \rightarrow \pi^+ p + p$, $t_{min} = 6.61 \times 10^{-3} (\text{GeV})^2$

if $H + p \rightarrow K^+ + p \rightarrow \Lambda + p$, $t_{min} = 6.24 \times 10^{-3} \text{ GeV}^2$

Assume:

Only difference is initial and final state masses, i.e. t_{min}

$$\text{so } \sigma = \sigma_{np} \cdot \frac{[e^{-bt_{min}}]_{np}}{[e^{-bt_{min}}]_{\Lambda p}}$$

$$\rightarrow \sigma = 0.92 \text{ mb} / 1.049 = .88 \text{ mb}$$

2. Elastic scattering of virtual lambdas inside H

$$|\langle H | \Lambda \Lambda \rangle|^2 = \frac{1}{8}$$

$$\frac{d\sigma}{dt} = A e^{-bt} \quad \rightarrow \quad \sigma = \frac{1}{8} \int_{t_{min}}^{\infty} A e^{-bt} dt \approx .5 \text{ mb}$$

$A = 29.5$
 $b = 7.2$

Two indistinguishable Λ 's: We should really sum amplitudes and then square, so we must multiply by a factor of 4.

$$\rightarrow \sigma = 2 \text{ mb}$$

Acceptance

→ Diffractive process produces Λ 's at small angles.

→ Heavy protons take most of Λ momentum and so stay close to detector axis.

→ π 's have low z momentum, and either travel out of apparatus by themselves or are swept out by magnet.

So need widest possible apertures, narrowest possible beam gap, and reasonably low field.

Incident H momentum ≈ 10 GeV/c.

Configuration 1: Split DC3

100 MeV/c in magnet

Narrow gaps as much as possible

Acceptance = 1.58%

Configuration 2:

Narrow gap in TSC1 by adding strips to X-counter

Acceptance = 2.6%

Need to check variation with $M_{2\pi}$, k_H .

TSC 1

DC5

TSC 1

DC5

1 meter

26.5 m m

DC4

25.5 m

DC4

24.5 m

Magnet 2

23.5 m

Magnet 2

DC3R

22.5 m

DC3R

DC3L

DC3L

166.0 cm

21.5 m

Target

Magnet 1

20.5 m

Magnet 1

ACCEPTANCE vs k_H

Acceptance as a function of incident H momentum, k_H . The Λ mass was fixed at 2.365 GeV/c².

Profile of acceptance across apparatus for $M_{2A}=2.365 \text{ GeV}/c^2$, $k_H=10.0 \text{ GeV}/c$.
 Each bin represents the effect of a particular element or process on the number of particles left to create a valid trigger.

Bin 1=total incident number - number not dissociating - events with recoil vetoes.

Bin 2=Bin 1 - vetoes from Λ decay or inelastic scattering inside target

Bin 3=Bin 2 - Λ decays to neutral particles - Λ decays past DC3L (first DC).

Bin 4=Bin 3 - number not making it through DC3L aperture

...Bin 8=previous Bins - losses due to each aperture

Bin 9=Final acceptance by hodoscope, where the trigger criterion is 4 hits in one dimension and at least 3 in the other.

The final acceptance is 1.88%.

Acceptance as a function of M_{2A} for incident H momentum of 10 GeV/c.

Number of H's Produced in pp Collisions

Many different channels:

1. Exclusive processes

$$pp \rightarrow \Lambda^0 \Lambda^0 K^+ K^+$$

2. Central production

$$pp \rightarrow H \bar{H} X$$

3. Resonance production and decay

$$pp \rightarrow N^{*+} p \rightarrow H \Xi^-$$

4. Coalescence

H coupling to baryon channels follows from wave function:

$$\Psi_H = \frac{1}{\sqrt{8}} (\Lambda \Lambda + \Sigma^0 \Sigma^0 + \Sigma^+ \Sigma^- + \Sigma^- \Sigma^+ + \Xi^- p + p \Xi^- + \Xi^0 n + n \Xi^0)$$

Similar to the production of deuterons and anti-deuterons. The H differs from deuteron production because of its much larger binding energy, and the replacement of a neutron with a Ξ^- .

$$\text{Vol in } k\text{-space} \sim k^3 \sim \frac{1}{R^3}$$

$$(R_c)_d = 1.78 \text{ fm}$$

$$(R_c)_H \approx .8 \text{ fm}$$

$$\text{so: } \frac{(\text{Vol})_H}{(\text{Vol})_d} \approx 10.$$

$$H/K = (H/d) \times (d/K)$$

$$= 10 \cdot (\Xi^-/K^+) \times (K^+_d/n) \times (d/K^+) \times \left(\frac{k^+}{k_d}\right)^2$$

$$= 10 \cdot \frac{1}{20} \cdot \frac{1}{15} \cdot \frac{1}{100} \approx 3.7 \times 10^{-4} \times \left(\frac{1}{2}\right)^2 = 1.48 \times 10^{-3}$$

could also have $\Xi^0 n$ so $\times 2$

$$\boxed{H/K \approx 3 \times 10^{-3}}$$

Total Number Seen

$$\begin{aligned} \#H's/day = & (\sigma \times (\#protons/area)) \times (\#H's/\#K's) \times (\#K's/day) \\ & \times (Acceptance) \end{aligned}$$

$$\sigma \approx 1mb$$

$$\#protons/area = 3.3 \times 10^{24} \text{ cm}^{-2}$$

$$\#H's/\#K's \approx 3 \times 10^{-3}$$

$$\#K's/day \approx 10^{10}$$

$$Acceptance \approx 1\%$$

$$\#H's/day \approx 900$$

Mass Resolution

$$\Delta m/m \approx 4\%$$

#H's
day