Search for the H-dibaryon

A Proposal to E871

Val Fitch Josh Klein Morgan May

DOE/ER/71019--T5-Pt.3C

AT03-76ER 71019

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

$S=-2$
$J^{\pi}=0^{+}$
$I=0$

Mass

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

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

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

QCD Analog of Magnetic Hyperfine Splitting in Hydrogen

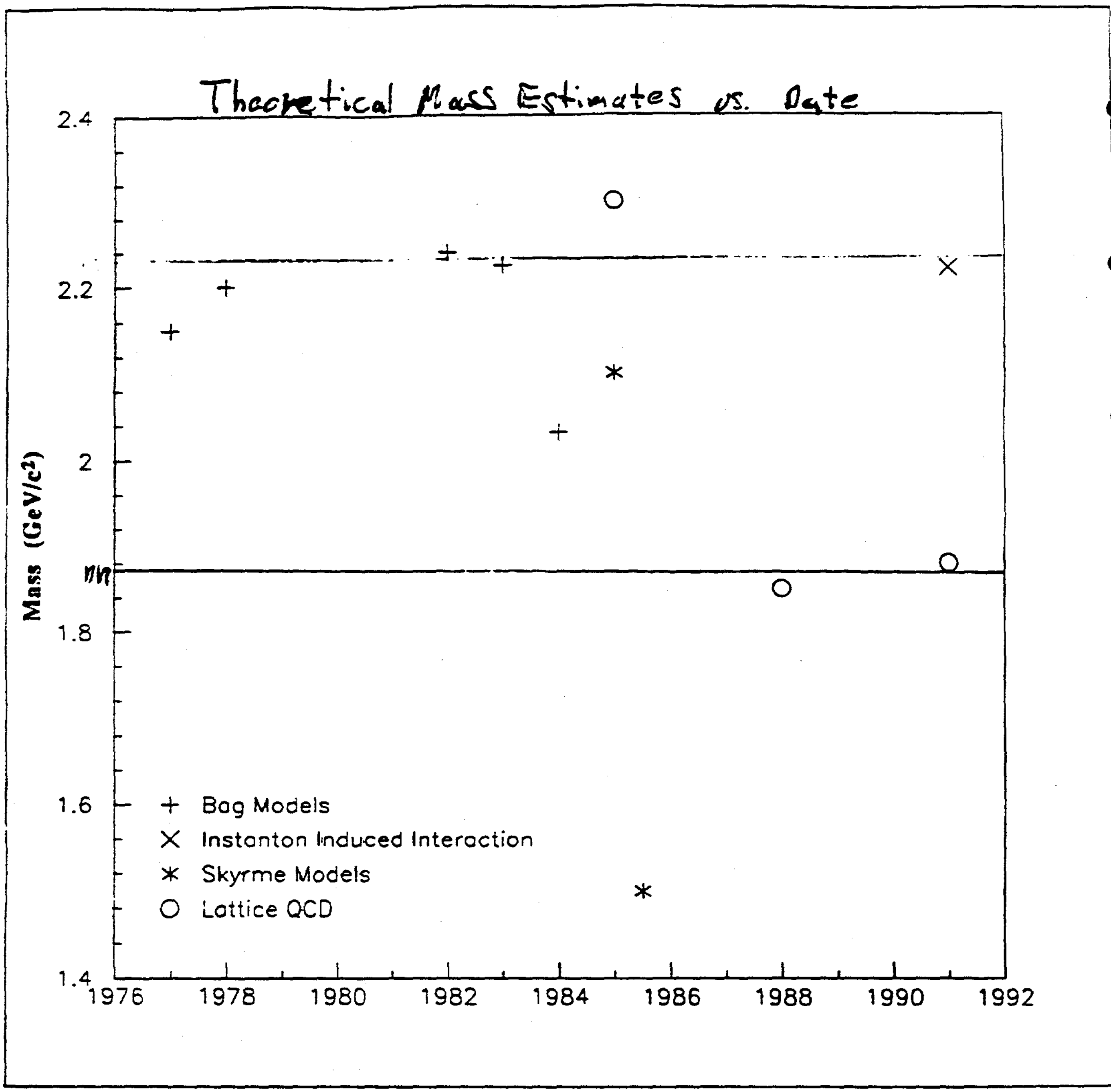
$E \sim \vec{I} \cdot \vec{J}$ — I = nuclear spin

$\Delta E \sim (F+1)$ — J = electron angular momentum

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

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

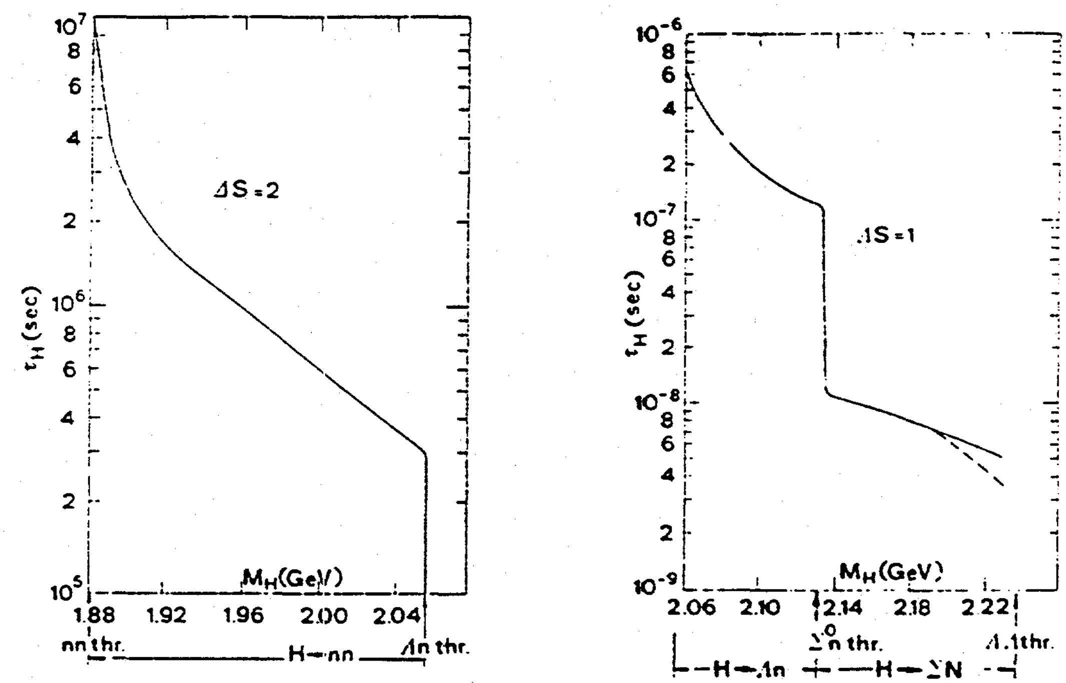
$J_p = 1/2,\ J_{\Delta} = 3/2$
$|M_p - M_{\Delta}| = 300$ MeV


Theoretical Mass Estimates vs. Date
Mass (GeV/c²)
2.4
2.2
2
1.8
1.6
1.4
1976
1978
1980
1982
1984
1986
1988
1990
1992
+ Bag Models
× Instanton Induced Interaction
* Skyrme Models
○ Lattice QCD

DISCLAIMER

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

$H \to nn$ (1.878 GeV/c^2)
$H \to \Lambda n$ (2.055 GeV/c^2)
$H \to \Sigma N$ (2.136 GeV/c^2)
$H \to \Lambda N \pi$ (2.195 GeV/c^2)



Above ΣN Threshold ΔI=1/2 Rule Predicts

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

but instead

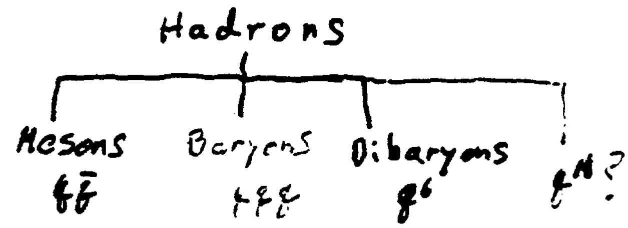
$$\Sigma^- p : \Sigma^0 n : \Lambda n :: 1 : 1.06 : -.61$$

First Violation of ΔI=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, ≈1/3 strange.*

Bjorken 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 $\frac{\langle E_K \rangle_3}{\langle E_K \rangle_2} \simeq .89$

→ 50-70 MeV/baryon lower than normal matter

Normal nuclei remain normal because of long lifetime.

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

'Neutron Feeding' releases energy.

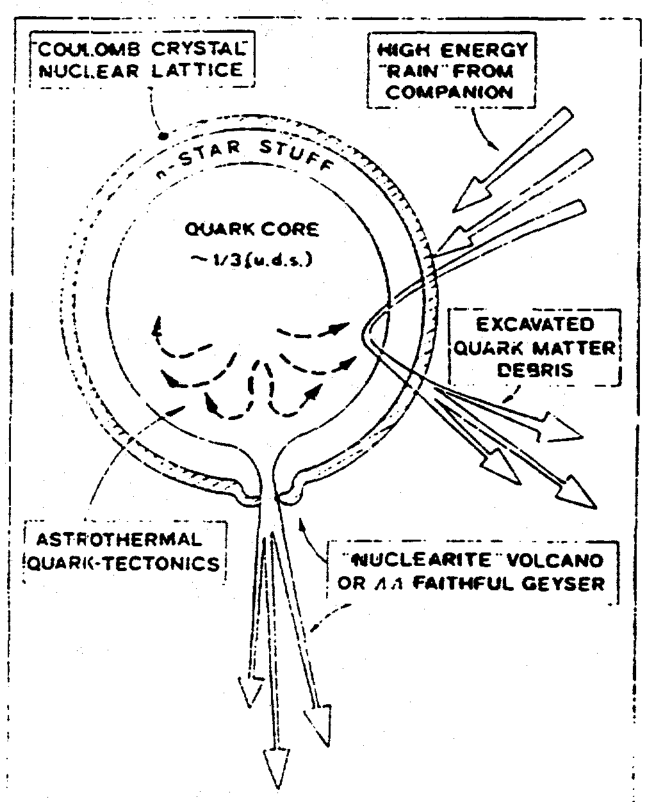
4. Astrophysical Explanations

Cygnus X-3
Hercules X-1

→ Hadronic signature of showers from point source.

orders of magnitude more μ's than expected from γ ... $\mu\nu$

→ 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.

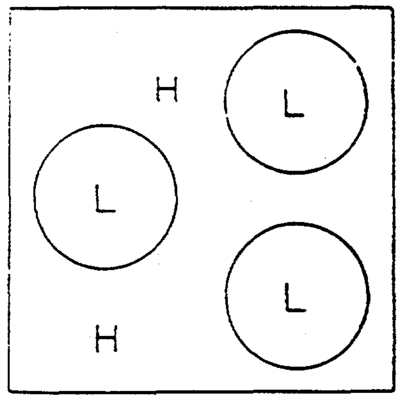


FIG. 1. Isolated expanding bubbles of low-temperature phase in the high-temperature phase.

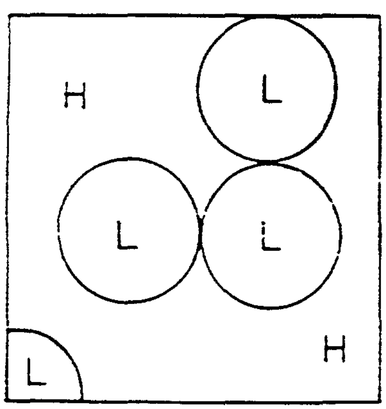


FIG 2. The expanding bubbles meet.

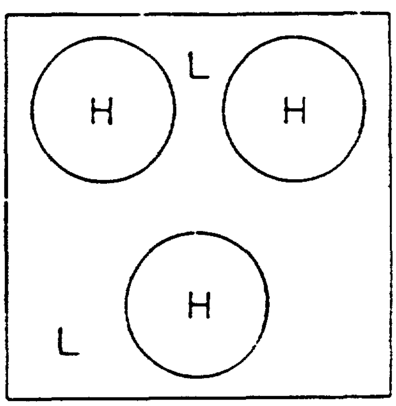


FIG. 3. Isolated shrinking bubbles of the high-temperature phase.

Experiments

I. Carroll *et al.*, 1978

Used reaction

$$pp \to K^+K^+X \quad \text{at} \quad 5 \text{ GeV/c}$$

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 $\bar{p}(3N) \to \Lambda^0\Lambda^0 KK$ has Q similar to

[illegible] MeV)

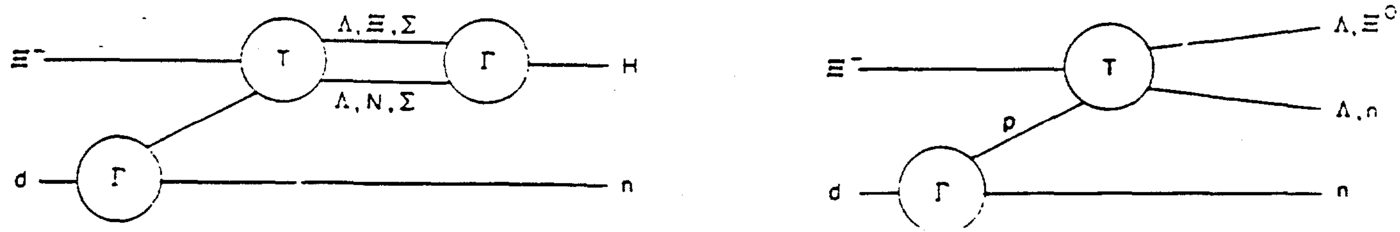
Limits: **For $\tau_H = \tau_\Lambda$, rate for** $\bar{p}A \to HX$ is $< 9 \times 10^{-5}$

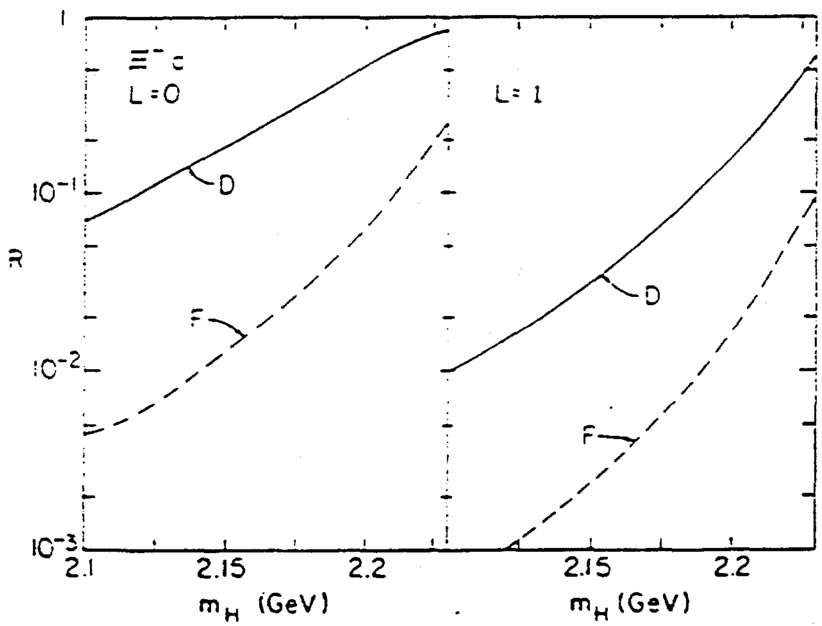
But rate for $\bar{p}A \to \Lambda^c\Lambda^c X$ is $< 4 \times 10^{-5}$

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

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

→ Neutron is monoenergetic.





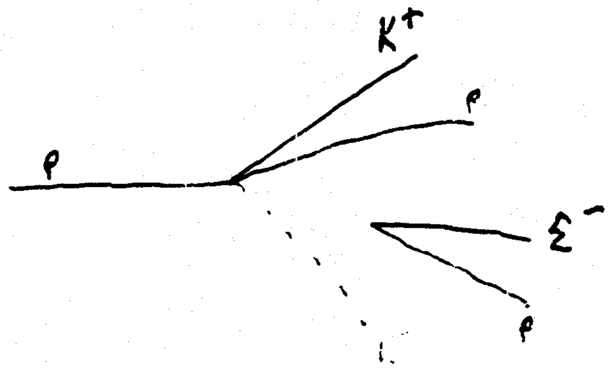
Branching ratios R for H production from S and P states of the $\Xi^- d$ atom, as a function of m_H. Results for one-boson-exchange models D and F are shown to provide an idea of the theoretical uncertainty, although model D is preferred (see text).

Sensitive only near threshold ($m_H \simeq m_{2\Lambda}$)

→ High neutron momenta difficult to detect

III. Shahbazian *et al.*, 1984

Creation and subsequent decay in propane bubble chamber



$\rightarrow M_H = 2.173\ GeV/c^2$

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

$M_{H^*} = 2.365\ GeV/c^2$
$\Gamma = .047\ GeV/c^2$

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

IV. Aoki *et al.*, 1990

K^- incident on emulsion target.

$K^- + (pp) \rightarrow H + K^+$

K^+ in this reaction has higher momentum than in

$K^- + p \rightarrow \Xi^- + K^+$

('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. ΛΛ Hypernuclei

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

→ Correct q. nos. to form H.

<u>Kerbikov (1984)</u>:

$$ {}^{6}_{\Lambda\Lambda}He \rightarrow H + \alpha $$

$$ \tau \ll \tau_w \; (\sim 10^{-10} s) $$

unless

$m_H \sim m_{\Lambda\Lambda}$ or $m_H \gtrsim m_{\Lambda\Lambda} - \ldots$

$\cong 2.221$

Observed Events

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

Fig.1(a)

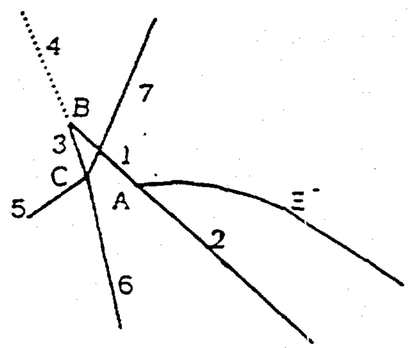


Fig.1(b)

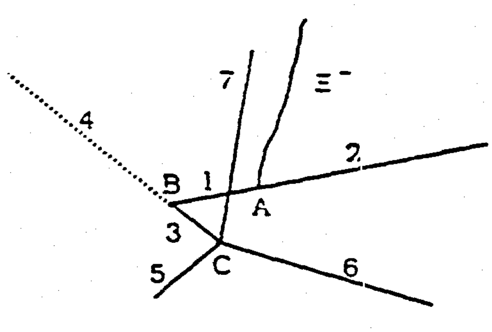


Fig.1(f)

Fig.1(c)

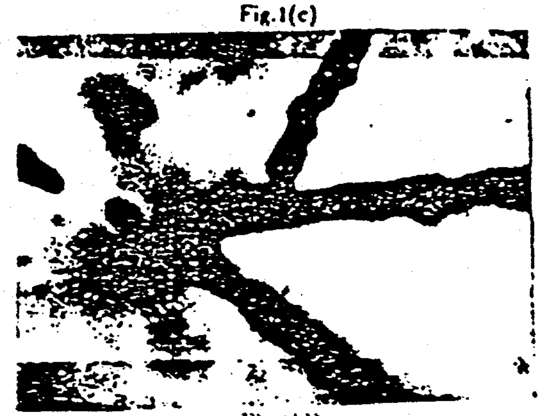


Fig.1(d)

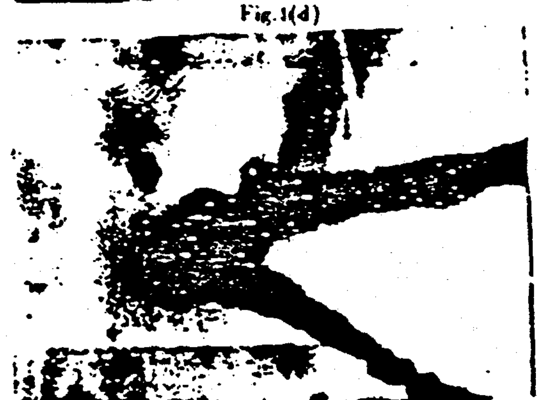


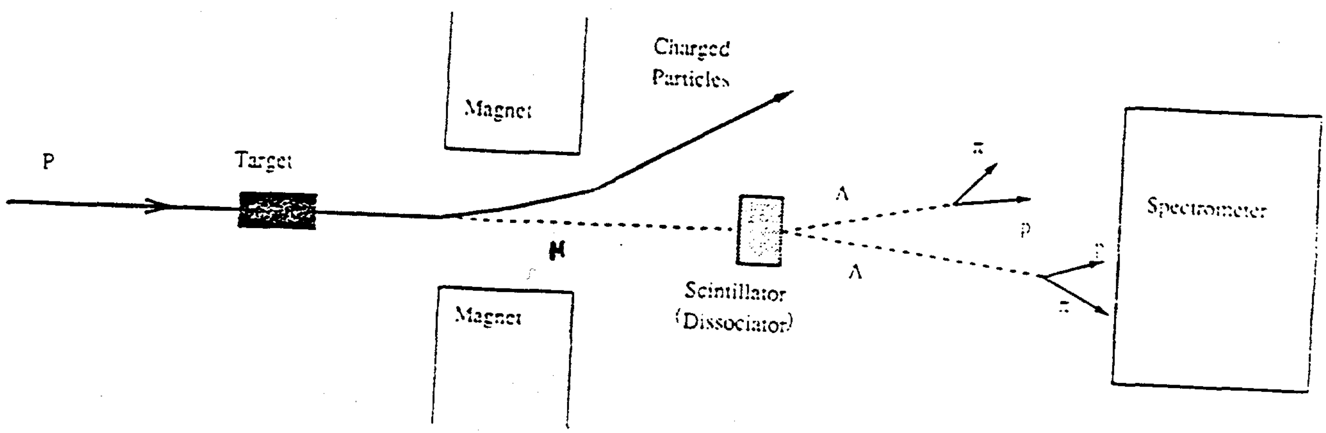
Fig.1(e)

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 × 0.5 × 10mm) 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*

→ *Diffractive Dissociation: $Hp \to \Lambda\Lambda p$, 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 $\rightarrow \frac{d\sigma}{dt} \sim e^{-bt}$;

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

if $n + p \rightarrow \Delta^0 + p \rightarrow \pi^- p + p$, $t_{min} = 1.01 \times 10^{-3}\ GeV^2$

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

Assume:

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

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

$\rightarrow \sigma =$ **0.92 mb/1.049 = .88 mb**

2. Elastic scattering of virtual lambdas inside H

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

$\frac{d\sigma}{dt} = Ae^{-bt} \rightarrow \sigma = \frac{1}{8} \int_{t_{min}}^{\infty} Ae^{-bt} dt \cong .5\ mb$

$A = 29.5$

$b = 7.2$

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

$\rightarrow \sigma =$ **2 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.

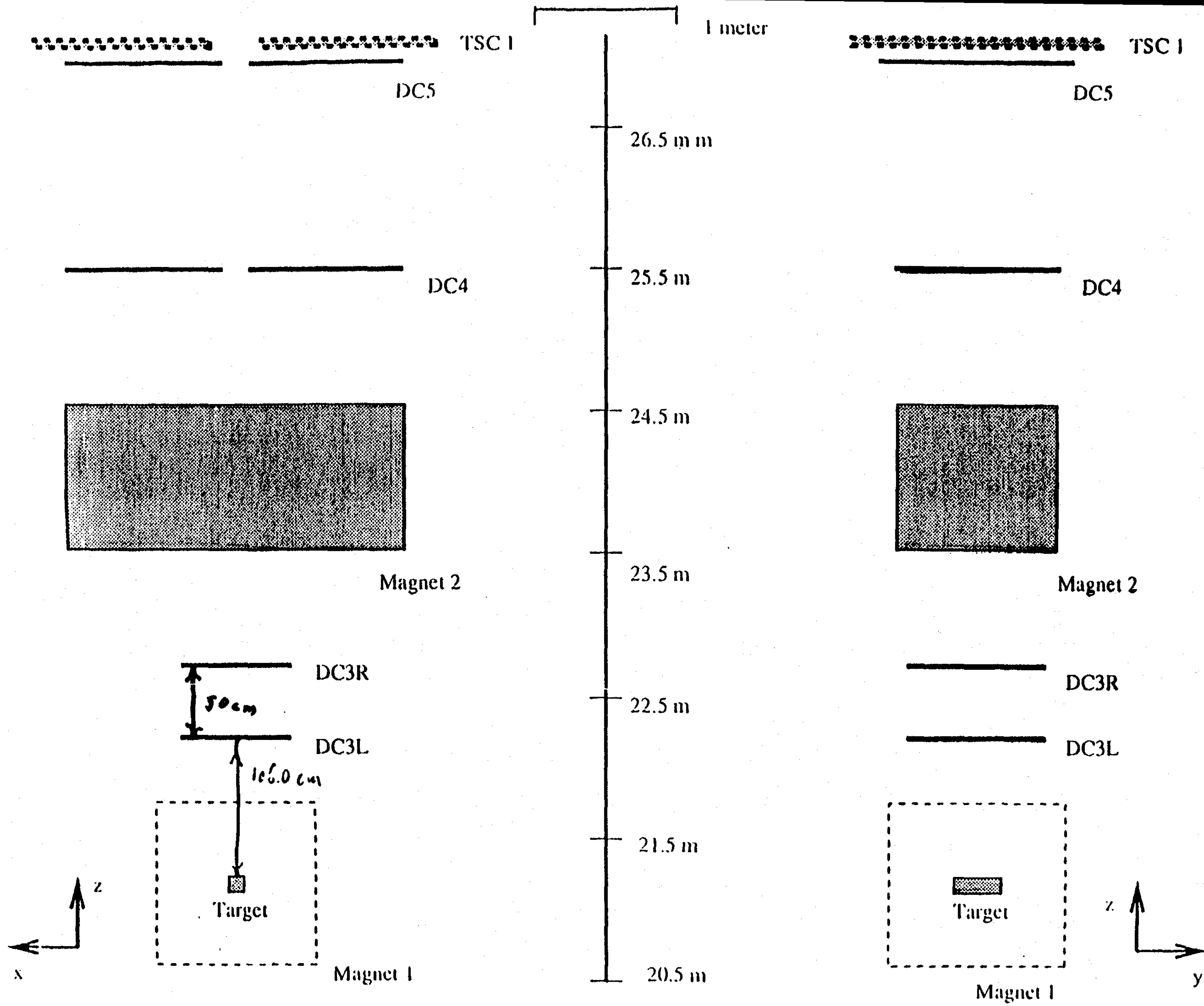
Configuration 1: Split DC3
100 MeV/c in Magnet
Narrow gaps as much as possible

Acceptance = 1.88%

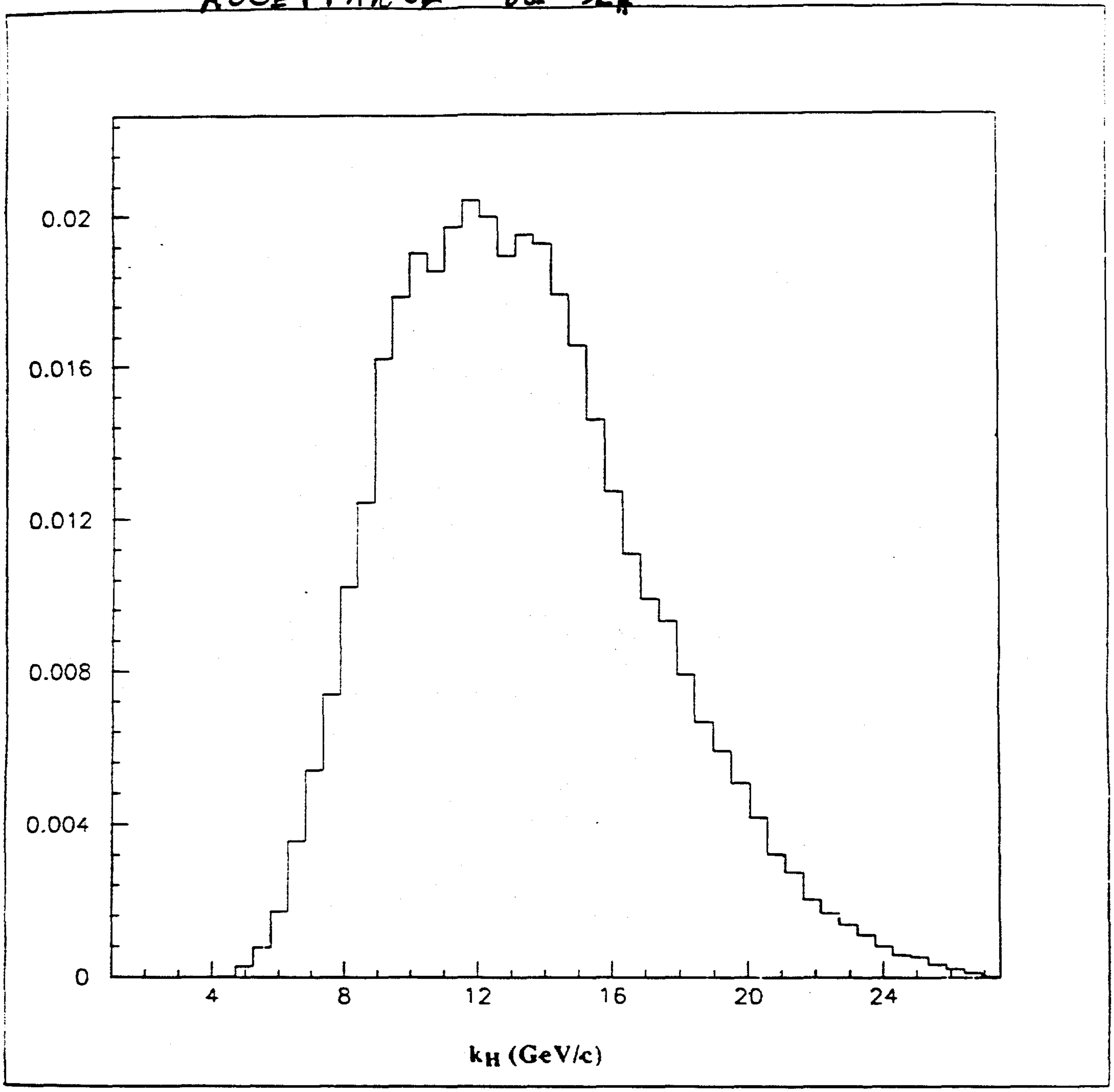
Configuration 2: Narrow gap in TSC 1 by adding strips to x-counter

Acceptance = 2.6%

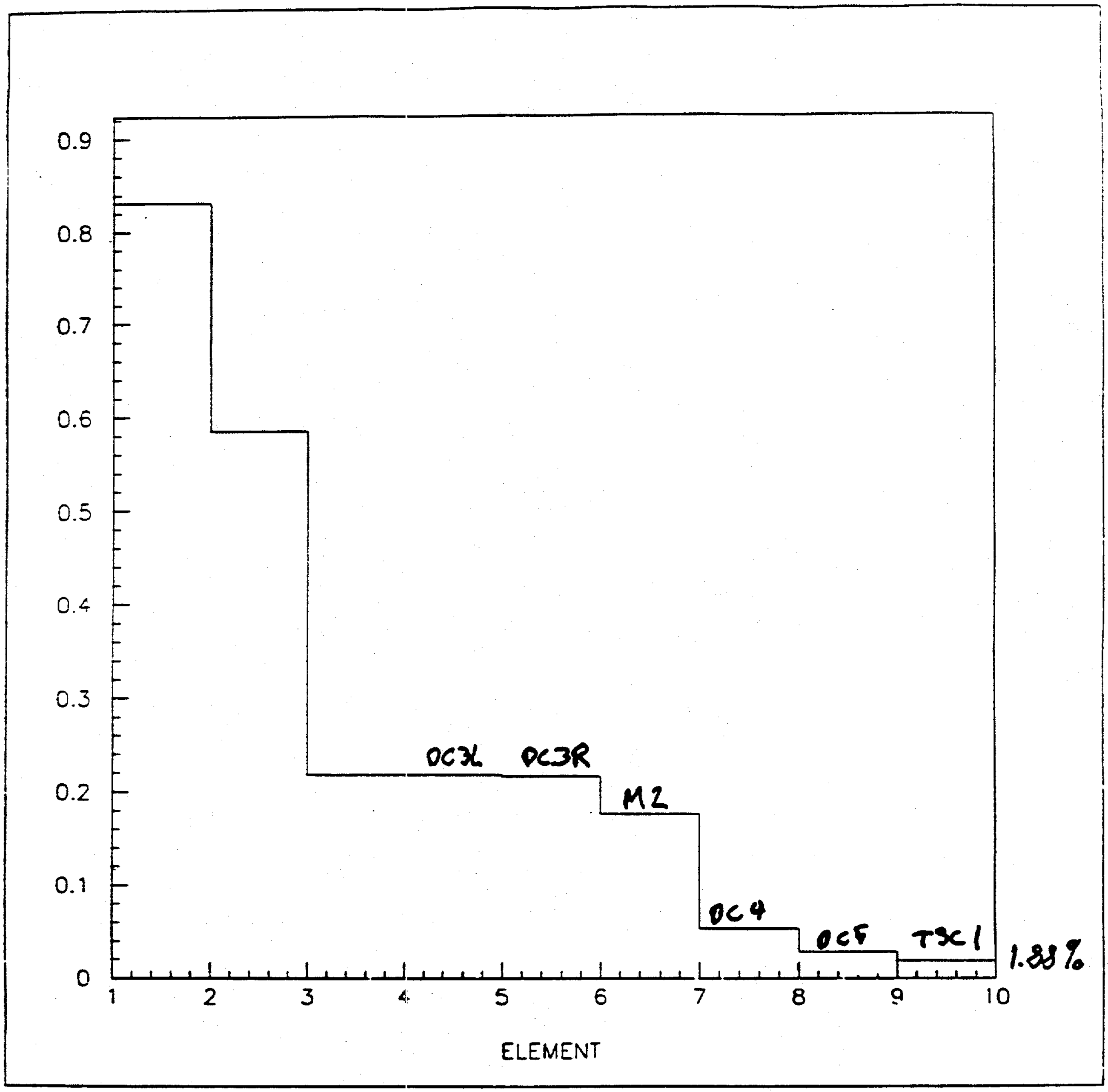
Need to check variation with $M_{2\Lambda}$, k_H.


TSC 1
DC5
DC4
Magnet 2
DC3R
50cm
DC3L
160.0 cm
Target
Magnet 1
z
x
1 meter
26.5 m m
25.5 m
24.5 m
23.5 m
22.5 m
21.5 m
20.5 m
TSC 1
DC5
DC4
Magnet 2
DC3R
DC3L
Target
Magnet 1
z
y

ACCEPTANCE vs k_H



Acceptance as a funcion of incident H momentum, k_H. The dilambda mass was fixed at 2.365 GeV/c^2.



Profile of acceptance across apparatus for $M_{2\Lambda}$=2.365 GeV/c^2, k_H=10.0 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

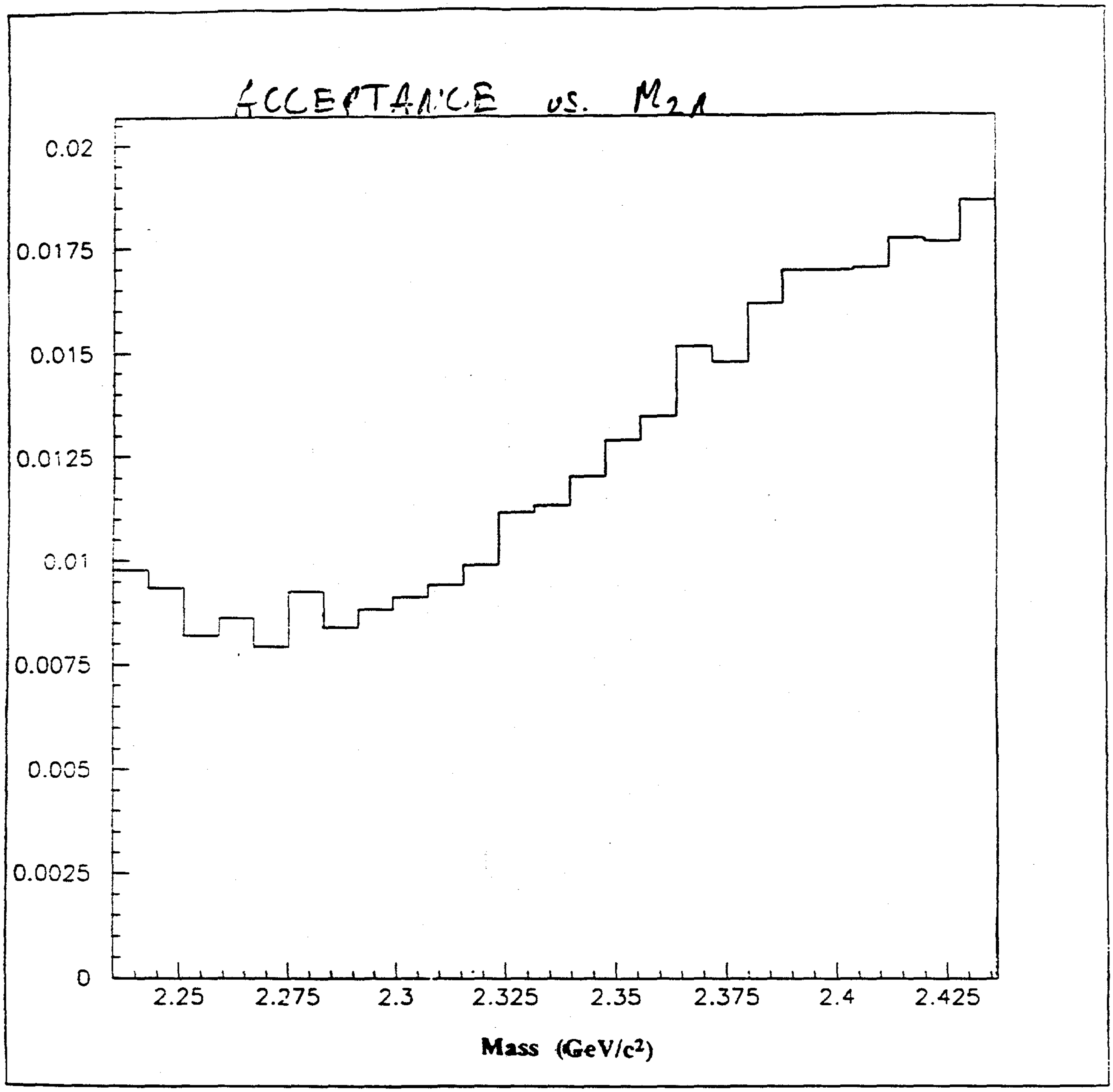
Bin 3=Bin2 - Λ decays to neutral particles - Λ decays past DC3L (first DC).

Bin 4=Bin3 - 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 $M_{2\Lambda}$ for incident H momentum of 10 GeV/c.

Number of H's Produced in pp Collisions

Many different channels:

1. *Exclusive processes* $pp \to \Lambda^0\Lambda^0 K^+ K^+$

2. *Central production* $pp \to H\bar{H}X$

3. *Resonance production and decay* $pp \to N^{**}p$
   $\quad \hookrightarrow H\Xi^-$

4. *Coalescence*

H coupling to baryon channels follows from wave function:

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

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

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

$(R_c)_d = 1.78$ fm

$(R_c)_H \simeq .8$ fm

so: $\frac{(k\text{-vol})_H}{(k\text{-vol})_d} \simeq 10.$

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

$$= 10\cdot(\Xi^-/K^+)\times(\Lambda/n)\times(d/K^+)\times\left(\frac{K^+}{K^0_L}\right)^2$$

$$= 10\cdot\frac{1}{20}\cdot\frac{1}{15}\cdot\frac{1}{100} \approx 3.7\times10^{-4}\times\left(\frac{1}{2}\right)^2 = 1.48\times10^{-3}$$

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

$$\boxed{H/K \approx 3\times10^{-3}}$$

Total Number Seen

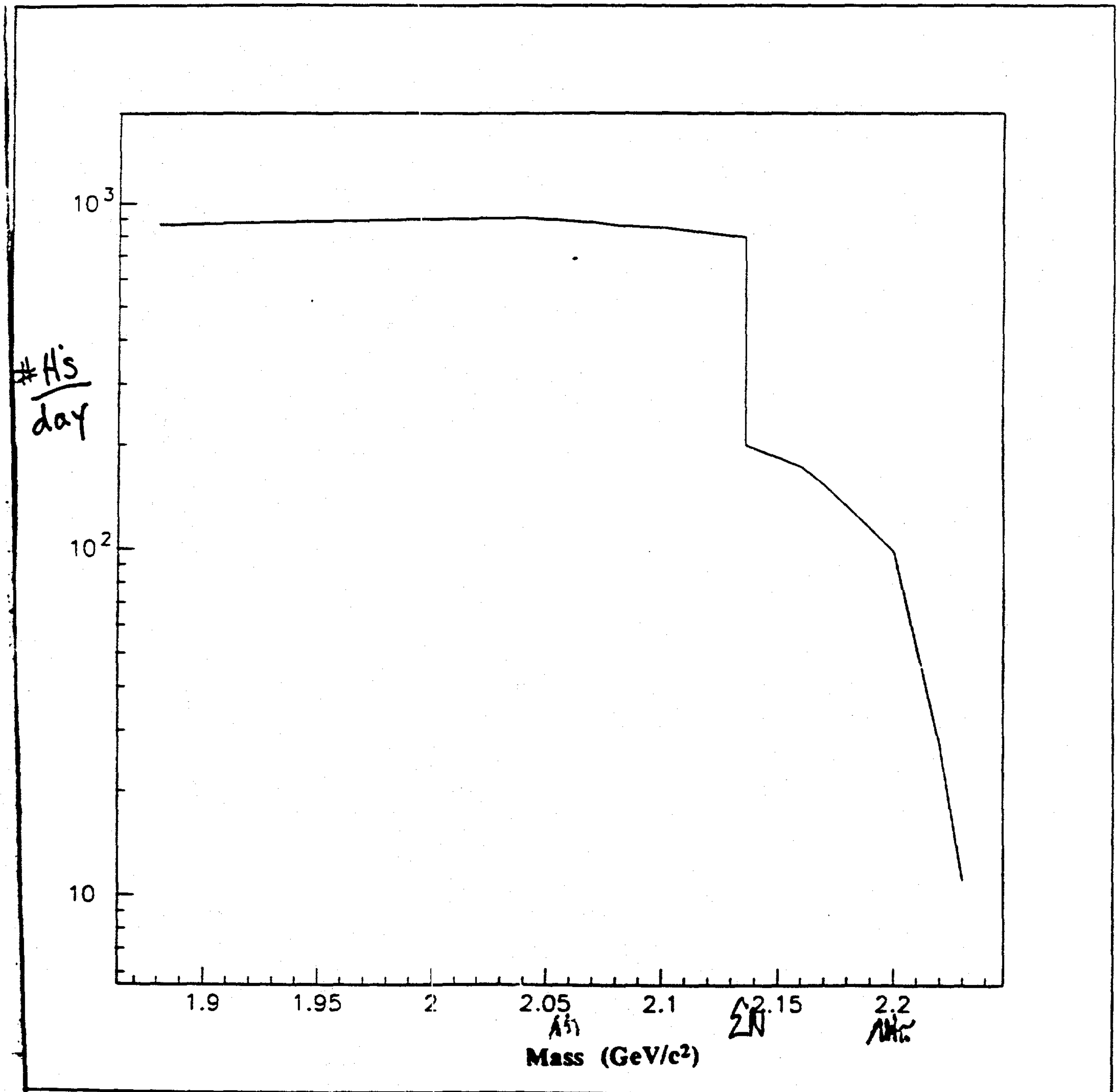
$$\#H's/day = (\sigma \times (\#protons/area)) \times (\#H's/\#K's) \times (\#K's/day) \times (Acceptance)$$

$\sigma \approx 1 mb$
$\#protons/area = 3.3 \times 10^{24}\ cm^{-2}$
$\#H's/\#K's \approx 3 \times 10^{-3}$
$\#K's/day \approx 10^{10}$
$Acceptance \approx 1\%$

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

Mass Resolution

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



10^3
10^2
10
1.9
1.95
2
2.05
2.1
2.15
2.2
Mass (GeV/c²)
#H's / day