Fermi National Accelerator Laboratory

FERMILAB-Pub-78/47-EXP
7560.596

(Submitted Phys. Lett.)

A SEARCH FOR NEW MASSIVE PARTICLES

R. Vidal, S. W. Herb, L. M. Lederman,
H. D. Snyder, J. K. Yoh
Columbia University, New York, New York 10027

C. N. Brown, W. R. Innes, R. D. Kephart,
K. Ueno, T. Yamanouchi
Fermi National Accelerator Laboratory
Batavia, Illinois 60510

D. M. Kaplan, A. S. Ito, H. Jöstlein
State University of New York at Stony Brook
Stony Brook, New York 11794

W. Smith
University of California, Berkeley, California 94720

June 1978

Operated by Universities Research Association Inc. under contract with the Energy Research and Development Administration

A SEARCH FOR NEW MASSIVE PARTICLES

R. Vidal, S. W. Herb, L. M. Lederman,
H. D. Snyder, J. K. Yoh
Columbia University, New York, New York 10027

C. N. Brown, W. R. Innes, R. D. Kephart,
K. Ueno, T. Yamanouchi
Fermi National Accelerator Laboratory
Batavia, Illinois 60510

D. M. Kaplan, A. S. Ito, H. Jöstlein
State University of New York at Stony Brook
Stony Brook, New York 11794

W. Smith
University of California, Berkeley, California 94720

We have searched for an almost stable, charged particle produced in 400 GeV proton-nucleus collisions. A total of 5×10^{10} light secondary particles were sampled in a secondary beam of 70 GeV/c momentum. If a 4.5 to 6.0 GeV mass particle is produced with a cross section comparable with the production cross section of the upsilon then this experiment places an upper limit on the lifetime of such a particle of about 5×10^{-8} sec.

It is now fairly well established that the Υ family[1] represents a $^3S_1$ state of an atom[2] composed of a new heavy quark, b, and its anti-quark, $\bar{b}$: Data on hadroproduction of the Υ and on the ratio of Υ'/Υ tend to favor $e_b = -1/3$ as does the recent observations of Υ at DESY via $e^+ + e^- \to \Upsilon$.[3] It has been argued[4] that the new quark may have completely different weak interactions and in particular, the new quark might form stable or highly metastable compounds with the lightest of the old quarks, e.g.

$$B^- = b\bar{u} \text{ and } B^+ = \bar{b}u$$

(where b is the new heavy quark and B is a meson). These objects should have a mass between 5 and 5.5 GeV. We have conducted a simple search for these objects in the N1 beam line of the Neutrino Lab at Fermilab.

Four-hundred GeV protons are incident upon a 10.5" Beryllium oxide target. The secondaries produced near zero degrees are transported to the detector by the Fermilab N1 beam line.[5] The secondary beam momentum was tuned to 70 GeV for the data taking. 70 GeV is chosen as it corresponds to the laboratory momentum of a 5.3 GeV object produced at $x = 0$ in the center of mass, a kinematic point where the upsilon production cross section is best known.

To detect heavy stable particles, we have used a simple apparatus (Fig. 1) which includes two Cerenkov counters modified to optically reject $\beta = 1$ particles and with a threshold at $\gamma = 12$. The Cerenkov counters do not respond to the very high rate ($\sim 10^7$/pulse) of pions which arrive in $\lesssim 1$ ns wide bunches every 18.9 ns (the period of the rf accelerating voltage in the Fermilab proton synchrotron). In addition we gate all counters off for ± 2 ns around each rf bunch, using a timing pulse derived from the accelerator rf system. The arrival of a particle delayed by ≥ 2 ns and with $0.996 < \beta < 0.998$ will count in both Cerenkov counters. To improve the rejection we also require a delayed count in each of two scintillation hodoscopes (vertical strips) placed at location BH_3 and BH_5 (Fig. 1). This provides beam definition and eliminates particles of wrong momenta.

To test the efficiency of the system, we set the beam momentum to 25 GeV/c where the anti-deuteron has very nearly the same β as a 5 GeV object of 70 GeV momentum. Figure 2 shows the resulting $\bar{d}$ peak. We periodically ran $\bar{d}$'s in order to check the efficiency of the vetoing and the Cerenkov counters.

In a data run of 16 hours at 70 GeV, we recorded 5×10^{10} light particles traversing the apparatus. This corresponds to $\sim 7 \times 10^{16}$ protons on target as measured by a secondary emission monitor. In the delay time interval of 5 to 13 ns, we observe masses of 4.0 to 6.5 GeV. However, the Cerenkov efficiency due to threshold on the one hand and the "$\beta = 1$" baffle on the other narrows the window at $p = 70$ GeV/c to 4.5 to 6.0 GeV. These acceptance limits were checked at both pion and $\bar{d}$ peaks by varying the gas pressure.

In total, only 3 events were recorded which passed a majority of the timing, directionality and pulse height requirements. Each of the 3 events failed at least one cut. On comparing with the anti-deuteron calibration runs it is unlikely that even one of the 3 events is a real slow heavy particle. The most reliable estimate for heavy stable particle production comes from the observed total pion flux.

$$\left.\frac{d\sigma_B}{dp\,d\Omega}\right|_{70\text{ GeV},\ 0^o} \cong \left.\frac{d\sigma_\pi}{dp\,d\Omega}\right|_{70\text{ GeV},\ 0^o} \cdot \frac{N_B}{N_\pi}$$

On the basis of a flux measurement,[6] we estimate the pion production cross section on our target to be ≈ 400 mb/GeV/sr. The 90% confidence level upper limit on $N_B/N_\pi = 2.3 / 5 \times 10^{10}$. Therefore

$$\left.\frac{d\sigma_B}{dp\,d\Omega}\right|_{70\text{ GeV},\ 0^o} < 2 \times 10^{-35}\ \text{cm}^2/\text{GeV/sr}$$

or

$$\left.\frac{E\,d^3\sigma_B}{dp^3}\right|_{x=0,\ p_T=0} < 3 \times 10^{-37}\ \text{cm}^2/\text{GeV}^2 .$$

The crucial comparison is with Υ production which is observed at the same kinematic point to be 1×10^{-36} cm^2/GeV^2 if a branching ratio $\Upsilon \rightarrow \mu^+\mu^-$ of 5% is assumed. Taking into account the lifetime that is required to survive the 920 meter flight path from a production target we have

$$\frac{B}{\Upsilon} < 1 \text{ if } \tau_{B^-} \gtrsim 2 \times 10^{-7} \text{ sec}$$

$$\frac{B^-}{\Upsilon} < 25 \text{ if } \tau_{B^-} \gtrsim 5 \times 10^{-8} \text{ sec.}$$

Simple theoretical considerations indicate that $\sigma(\overline{B}B)$ should exceed $\sigma(\Upsilon)$ by at least an order of magnitude.[7] This seems to be the case in the ratio of hadronic production[8] of $D\overline{D}$ versus Ψ. The failure to find a signal[9] in this search thus leads to the conclusion that the lifetime of such a B^- meson is $\lesssim 5 \times 10^{-8}$ sec.

We would like to thank the many people at the Fermi National Accelerator Laboratory who contributed to the successful running of this experiment. We thank particularly D. Ritchie and the Fermilab Computing Department for their work on our on-line software. This work was supported by the U. S. Department of Energy and the National Science Foundation.

REFERENCES

[1] S. W. Herb et al., Phys. Rev. Lett. 39, 252 (1977).

W. R. Innes et al., Phys. Rev. Lett. 39, 1240 (1977).

[2] E. Eichten and K. Gottfried, Phys. Lett. 66B, 286 (1977).

C. Quigg and J. L. Rosner, Phys. Lett. 71B, 153 (1977).

[3] Ch. Berger et al., DESY preprint, DESY 78/21, May 1978.

C. W. Darden et al., DESY preprint, DESY 78/22, May 1978.

[4] R. N. Cahn, Phys. Rev. Lett. 40, 80 (1978).

[5] J. G. Branson, Thesis, Princeton University, May 1977.

[6] H. E. Fisk, D. Nease, Caltech-Fermilab Experiment 21, private communication.

[7] This argument is reviewed in a series of lectures by C. Quigg, Fermilab CONF-78/37 (1978).

[8] Compare ψ production, D. C. Hom et al., Phys. Rev. Lett. 37, 1377 (1976), with charmed meson production: P. Alibran et al., Phys. Lett. 74B, 134 (1978), T. Hansl et al., Phys. Lett. 74B, 139 (1978), P. C. Bosetti et al., Phys. Lett. 74B, 143 (1978), and M. Shavitz, Vanderbilt Conference Proceedings, 1978.

[9] Our result is in agreement with a recent search carried out at Fermilab by D. Cutts et al., Fermilab PUB-78/45-EXP (May 1978).

FIGURE CAPTIONS

Fig. 1 Schematic diagram of the apparatus. S_i are veto scintillation counters, BH_i are multielement beam hodoscopes, and C_i are partially differential Cerenkov counters.

Fig. 2(a) Yield of anti-deuterons in a calibration run with the beam line tuned to 25 GeV, plotted versus time delay with respect to the prompt pions and equivalently mass of the heavy particle.

Fig. 2(b) Three events mentioned in text recorded with the beam line set for 70 GeV.

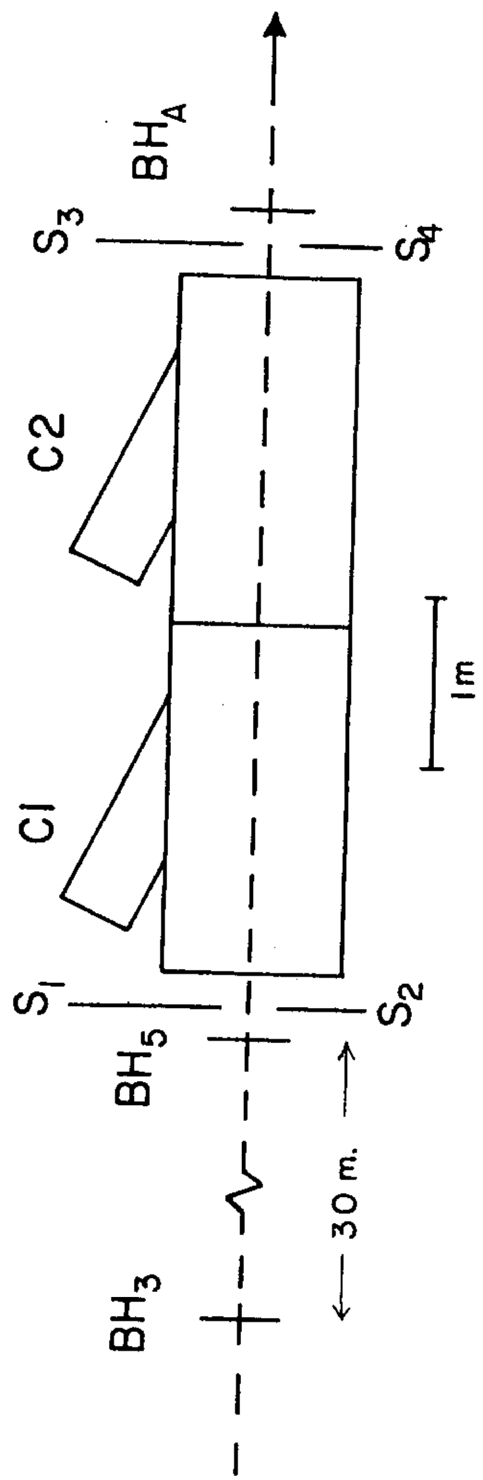

Fig. 1

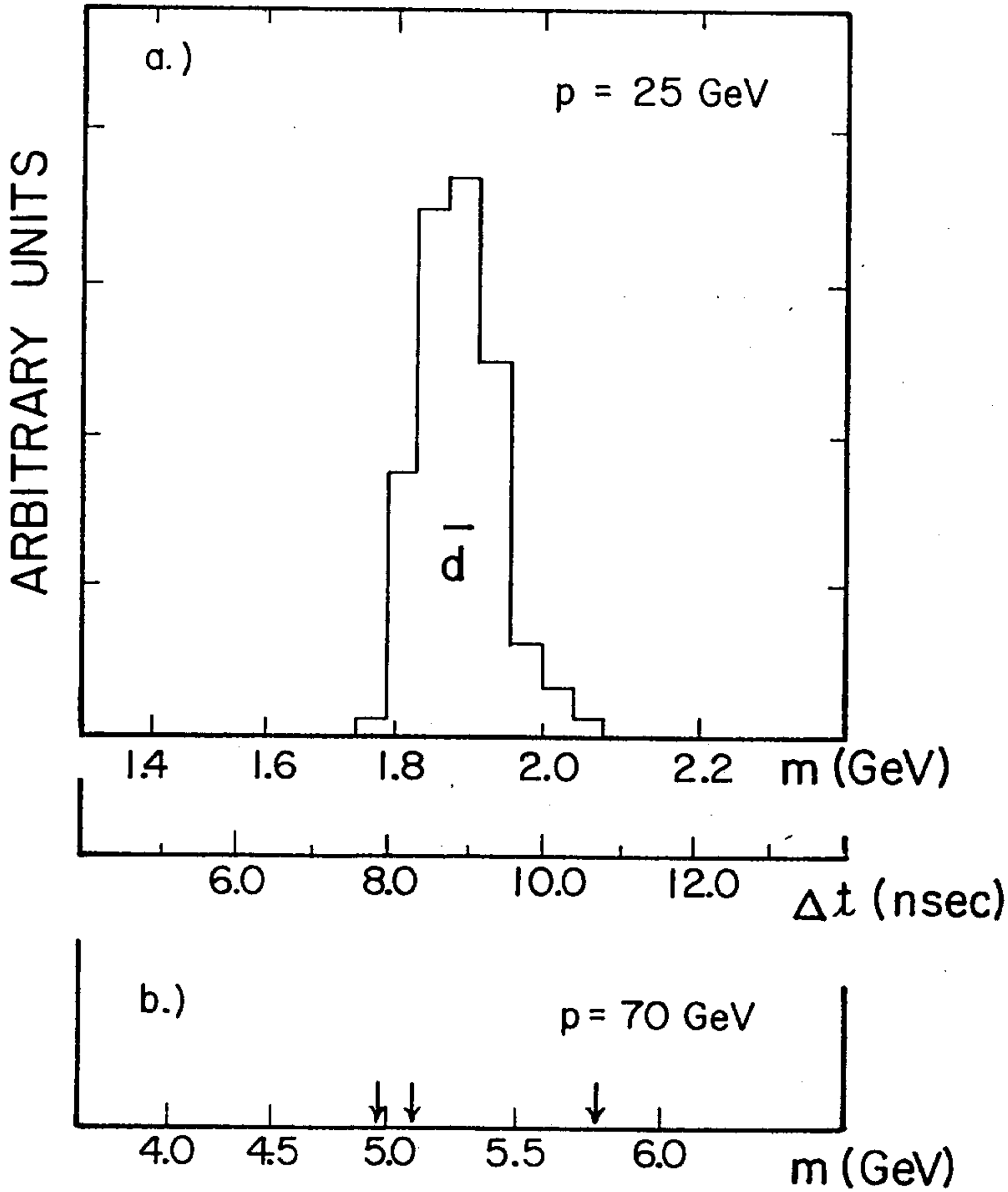
a.)
p = 25 GeV
ARBITRARY UNITS
d̄
1.4
1.6
1.8
2.0
2.2
m (GeV)
6.0
8.0
10.0
12.0
Δt (nsec)
b.)
p = 70 GeV
4.0
4.5
5.0
5.5
6.0
m (GeV)

Fig. 2