



## One Researcher's Personal Account

by  
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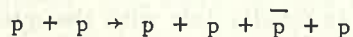
**T**he decision to look for quarks was a natural one for red-blooded experimentalists in 1964. Our considerations were, as always, modulated by the presence of T. D. Lee, who reminded us that quarks, or at least Fundamental Triplets, need not have curious charge. How to proceed was the subject of lively discussion at Nevis Laboratory\*, the most active participants in the discussion being W. Lee, S. Devons, J. Rosen and the newly arrived C. C. (Sam) Ting. One of the issues was the experimental

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approach; another was the influence of Fermi motion, i. e., the ability of the nucleus to provide some of the energy required to produce these heavy objects. We knew that if the Brookhaven AGS were capable of making quarks, it would not be with much energy to spare (5.7 GeV is the maximum available energy for particle production in a p-p collision). Thus we had to be prepared for a very small production rate. On the one hand, the experiment required extremely sensitive apparatus -- sensitive to quarks but incapable of being spoofed by a "miraculous" combination of events generated by the ordinary AGS radiation. On the other hand, we had to try to understand how deeply we were probing for these new objects.

Somewhere during the corridor discussions came the idea that we should study Fermi motion by producing antiprotons with incident protons too low in energy to produce them in free nucleon-nucleon collisions. Before I really knew what was happening Wonyong Lee arranged (in his old home territory) a run at the Berkeley Bevatron -- an accelerator well-tuned to producing antiprotons. With the enthusiastic assistance of Trilling's group, he quickly set up a sensitive  $\bar{p}$  detection system and in just a few hours we easily repeated the Segre-Chamberlain experiment (albeit 10 years too late!).

The 6 GeV Bevatron is barely energetic enough to produce  $\bar{p}$ 's via the reaction



and lowering the energy to 5 GeV would make the above reaction impossible. However, if the target proton is part of a Cu-nucleus, it can be viewed as moving about; and if it happens to be heading towards the incident projectile, it adds considerable energy to the collision. We naturally kept counting  $\bar{p}$ 's with reduced intensity as we lowered the energy of the Bevatron until we reached 3.5 GeV. At this point the accelerator called a halt -- no self-respecting 6 GeV accelerator can work at 3 GeV!

It was time to go to an accelerator that made a specialty of supplying 3 GeV protons, e. g., the 3 GeV PPA in Princeton. Pierre Piroué and his student, Stu Smith, were delighted to help out, as was the congenial Director, Milton White, who made the extra running time available. We found  $\bar{p}$ 's at 2.9 GeV incident energy, requiring an assist (via Fermi motion) of effectively 2 GeV laboratory energy. It is clear that we were thereby sensitive to a very small part of the nuclear wave function, the probability for such collisions being only  $10^{-4}$  of a typical collision.

The implication for an AGS quark experiment

was clear: the same nuclear tail with incident protons of 30 GeV energy would make  $\sim 10$  GeV available in the center-of-mass system at BNL -- the equivalent of a 75 GeV accelerator.

A smooth extrapolation of the resulting momentum distribution would make the 30 GeV AGS look like a 200 GeV accelerator for  $10^{-7}$  of the collisions. (I congratulated Maurice Goldhaber on his directing an accelerator with  $10^{12} \times 10^{-7} = 10^5$  protons/pulse of 200 GeV in 1965!)

We thought this would be incredibly interesting to nuclear theorists and, in fact, we were inundated with one postcard requesting a reprint. Conclusion: theorists aren't too interested in improbable tails of nuclear wave functions.

While we were chasing  $\bar{p}$ 's, Ting, aided by a postdoc, John Eades, and a graduate student, David Dorfin, was designing the electronic logic for the quark search. We renamed it: "Search for Massive Particles", using high mass (and meta-stability) rather than funny charge as the key. This, we reasoned, was more general and included  $q = 2/3, 4/3, \text{etc.}$ , as well as  $q = 1$ . We treated the logic to an exhaustive series of war games, trying to invent improbable processes that would spoof the system. When some miraculous event succeeded, we would modify the logic to kill it. The details are in the paper. Having a complex logic with independent and redundant determinations of momentum and velocity, one is finally left with the question: Yes, but is it efficient? How do we know that it would work the way it should in the eventuality that we do not detect the quark?

The answer, we found, was to detect the antideuteron, surely a rare, massive and certain-to-be-there object: a perfect foil for the experiment. In fact, the apparatus was an overkill for  $\bar{d}$ 's. When tuned for  $m = 2m_p$ , the  $\bar{d}$  peak stood out like Mt. Blanc on a clear day. Various checks were made to remove any doubts (a few counts at the correct mass are really not enough to prove the existence of a particle unless you are already convinced it exists): (1) A direct comparison was made with the copious  $d^+$  counts under identical conditions; (2) The variation of velocity with momentum (a function of mass via the formula  $p = mv$ ) was verified; (3) Any possible simulation of  $\bar{d}$  by  $\pi^-$  which constituted 99% of the beam was ruled out experimentally; (4) The  $\bar{d}$  was observed to have the anomalously large absorption well-known for  $\bar{p}$ 's and  $\bar{n}$ 's.

Ting, indefatigable, insisted we pursue the search for antitritons ( $\bar{t}$ ). We had already used up 40 of the

50 hours allotted to us by BNL. In the next 10 hours we had three candidates for the  $\bar{T}$  -- not enough to prove its existence. An apocryphal story has it that the AGS crews carried our apparatus off the floor while Ting was still trying desperately to amass a few more  $\bar{T}$  events. (Five years later, Soviet scientists at Serpukhov found anti- $\text{He}_3$ . This was ceremoniously recorded in Soviet Archives as a Notable Discovery.)

The theoretical significance of  $\bar{d}$  production is a matter of nuclear physics. A crude calculation based on the successive production of  $\bar{p}$  and  $\bar{n}$  with subsequent "pick-up" was presented in David Dorfin's thesis.\*

The news of  $\bar{d}$ 's rapidly spread and intense public interest in antimatter was evidenced by the great deal of coverage this not-too-surprising result received. The news was "published" by the Director of BNL at a hearing of the Congressional Joint Committee on Atomic Energy, early in March, 1965. Press coverage brought letters from Johannesburg, Sydney, Calcutta, Novosibirsk. Much of the correspondence was generated by my (unfortunate) remark to the American Institute of Physics press officer: "The existence of antideuterons is the final proof that antipeople could possibly exist." That's when, as they say in the Navy, the ship hit the fan.

Letters poured in ... 30% were from people who had seen antipeople, 45% were high school students doing term papers, 25% were serious inquiries concerning the philosophical, practical, technological, anthropological or religious significance of the discovery. Did it help science? As everyone knows, the science budgets in 1966 and 1967 were the highest in history!

The main result of our research was, of course, the establishing of the absence of any evidence for the existence of massive particles; i. e., particles of charge  $3/4e$  or  $1e$  and which live long enough to traverse the apparatus.

As in love, absence makes the heart grow fonder and the Physics Community immediately responded by beginning the construction of more powerful accelerators with which to pursue this search. At this writing, the 500 GeV accelerator at Batavia and the Intersecting Storage Rings (effective energy 1500 GeV) at CERN are ready to write the next chapter in this quest for the ultimate constituents of matter. □

\* David Dorfin, Nevis Report No. 159.