CONF-8806204--5

BNL-41757

THE SEARCH FOR PROTON DECAY - A LOOK BACK*

BNL--41757

DE89 001606

Maurice Goldhaber
Brookhaven National Laboratory**
Upton, NY 11973

My young friend Fred Reines and I have been interested in the question of proton stability for more than a third of a century, when we made the first explicit attempt to test it. At that time there was a widespread belief that the proton is absolutely stable, as expressed first by Weyl in 1929, ten years later by Stueckelberg, and ten years later again by Wigner. But what was the reason for this belief? One might say, these physicists felt it in their bones that the proton is stable, but the bones, one can estimate, are only sensitive to proton life times $\lesssim 10^{16}$ years; for shorter lifetimes one might have to file an environmental impact statement before filling a lecture hall. It is interesting to see how Wigner argued (Proc. Am. Philos. Soc. 93, 521 (1949), p. 525, footnote):

"It is conceivable, for instance, that a conservation law for the number of heavy particles (protons and neutrons) is responsible for the stability of the protons in the same way as the conservation law for charges is responsible for the stability of the electron. Without the conservation law in question, the proton could disintegrate, under emission of a light quantum, into a positron, just as the electron could disintegrate, were it not for the conservation law for the electric charge, into a light quantum and a neutrino."

---

*Dedicated to Fred Reines on his seventieth birthday.

**Under Contract No. DE-AC02-76CH00016 with the U.S. Department of Energy.

To be published in the Proceedings of the 13th International Conference on Neutrino Physics and Astrophysics.

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

One can do better than the bones either by an indirect argument on the absence of "spontaneous" fission in Thorium or by direct measurements which Fred, the late Clyde Cowan and I started in the summer of 1954 while I was visiting Los Alamos. This is what we said (F. Reines, C.L. Cowan, Jr. and M. Goldhaber, Phys. Rev. 96, 1157 (1954):

"It has often been surmised that there exists a conservation law of nucleons, i.e., that they neither decay spontaneously nor are destroyed or created singly in nuclear collisions. In view of the fundamental nature of such an assumption, it seemed of interest to investigate the extent to which the stability of nucleons could be experimentally demonstrated."

Note that our aim was modest. We only wanted to test to what "extent the stability of nucleons could be experimentally demonstrated". When later theoretical predictions of proton decay came along and candidates for proton decay were quickly found our modesty paid off: We always remembered that the most important thing about a candidate was his background.

Wigner's suggestion of a possible decay mode for the electron, as well as other potential electron decay modes, were investigated at Brookhaven with Ed der Mateosian and by many others, including Fred and his collaborators and Prof. Pomansky, whose health, unfortunately, did not permit him to come here to talk about this question in detail. But if anyone of us had succeeded to find electron decay you might have heard about it.

At first proton decay was usually investigated parasitically in neutrino detectors, with few exceptions. Over the next dozen years the decay limits were improved considerably. A summary table of such experiments given in a paper by Gurr et al., is reproduced here.

One early dedicated experiment is that of Backenstoss et al., following an interesting speculation of Yamaguchi. Once a question is dressed up as a theory it's easier to fund dedicated experiments.

With the advent of the Grand Unified Theories (Pati and Salam 1973, Georgi and Glashow 1974) which predict that the proton has a finite lifetime, a lot of physicists rushed underground; they rushed because the predicted lifetime was so short.

Table I. Summary of nucleon half-life experiments.

Experimenters	Nucleon half-life (yr)	Nucleon decay detection method	Nucleon source
Goldhaber (1954) (private communication)	$>1.4\times10^{18}$	Spontaneous fission of Th^{232} after excitation by nucleon decay. Assumes that the rearrangement energy upon loss of a nucleon is sufficient to cause fission of the residual nucleus.	
Reines, Cowan and Goldhaber (1954) (Ref. 4)	$>1\times10^{22}$	High-energy decay fragment. Liquid scintillation, 30 m below surface.	Toluene in detector and surrounding paraffin.
Reines, Cowan and Kruse (1957) (Ref. 5)	$>4\times10^{23}$	Proton decay in deuteron. High energy fragment plus neutron left over from deuteron after decay of proton. Delayed coincidence and liquid scintillation, 61 m below surface.	
Backenstoss, Frauenfelder, Hyams, Koester, and Marin (1960) (Ref. 6)	$>2.8\times10^{26}$	High-energy fragment; upward going particles. Cerenkov and scintillation, 800 m below surface. At least 250 MeV assumed to be available to decay particle. Result based on combined measurements for neutrons and protons.	Water, Lead, and rock.
Giamati and Reines (1962) (Ref. 7)	$>1\times10^{26}$ to $>7\times10^{27}$ depending on mode.	High-energy fragment. Liquid scintillation with anticoincidence shield, 585 m below surface.	Decalin in detector and surrounding iron.
Kropp and Reines (1964) (Ref. 8)	$>6\times10^{27}$ to $>4\times10^{28}$ depending on mode.	High-energy fragment. Liquid scintillation with anticoincidence shield, 585 m below surface.	Decalin in detector and surrounding iron.
Dix and Reines (private communication)	In progress.	Neutron left over from deuteron after decay of proton. Not dependent on decay mode.	Heavy water in detector.
Present experiment	$>2\times10^{26}$ to $>8\times10^{29}$, depending on mode.	High-energy fragment. Liquid scintillation, 3200 m below surface. Horizontally going particles.	Surrounding rock, mineral oil scintillator, and detector box.

REPRODUCED FROM
BEST AVAILABLE COPY

Nowadays neutrinos are studied in symbiosis with proton decay, both in their own right, and also because their interactions form the most serious background in proton decay experiments.

Our experiment (the IMB experiment) is now nearly ten years old and the number of collaborators has waxed and waned with time. Here is a snapshot of what our collaboration looked like about two years ago:

R.M. Bionta, G. Blewitt, C.B. Bratton, D. Casper, P. Chrysicopoulou, R. Claus, B.G. Cortez, S. Errede, G.W. Foster, W. Gajewski, K.S. Ganezer, M. Goldhaber, T.J. Haines, T.W. Jones, D. Kielczewska, W.R. Kropp, J.G. Learned, E. Lehmann, J.M. LoSecco, H.S. Park, F. Reines, J. Schultz, S. Seidel, E. Shumard, D. Sinclair, H.W. Sobel, J.L. Stone, L. Sulak, R. Svoboda, J.C. van der Velde and C. Wuest.

We had decided to build a large enough detector to reach a proton lifetime of $\sim 10^{33}$ years, much larger than the lifetime predicted by the minimal SU(5) theory, which is subject to approximations and uncertainties in our knowledge of QCD parameters. For the decay mode $p \to e^+ + \pi^\circ$ Marciano estimated a partial lifetime $4.5 \times 10^{29} \pm 1.7$ years. When we reached a limit several hundred times the central value of this prediction it was generally accepted that minimal SU(5) theory was refuted. Since Kamiokande and Fréjus have also not seen this decay mode, the combined results give a limit of ~ 1000 times larger then the central theoretical value. Many other potential decay modes have also been studied. Some are discussed by Prof. Barloutaud in his report to this Conference.

The vital question of proton stability is still with us and it is important to continue attempts, both experimental and theoretical, to answer it.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.