Title
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Publication Date
1993-07-01

LBL-34708
UC-484

Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

Physics Division

Presented at the Conference on the Bubble Chamber and Its Contributions to Particle Physics, Geneva, Switzerland, July 14–18, 1993, and to be published in the Proceedings

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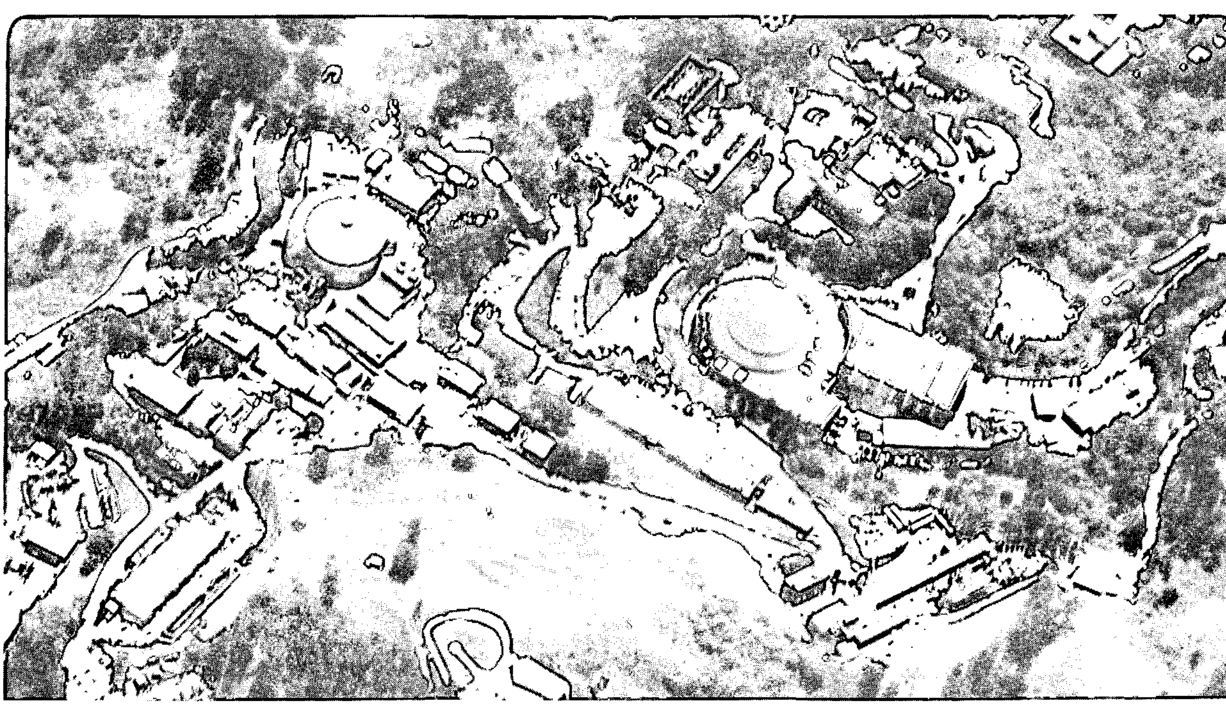
July 1993



Prepared for the U.S. Department of Energy under Contract Number DE-AC03-76SF00098

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LBL-34708
DOE Dist. Cat. UC-414

CONFERENCE ON THE BUBBLE CHAMBER
AND ITS CONTRIBUTIONS TO PARTICLE PHYSICS
alias
"BUBBLES 40"

THE DISCOVERY OF MUON CATALYSIS OF NUCLEAR FUSION

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14 - 18 July 1993 - CERN, Geneva Switzerland

*This work was supported by the Director, Office of Energy Research, Office of High Energy and Nuclear Physics, High Energy Physics Division, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

"Bubbles 40", The Discovery of Muon Catalysis of Nuclear Fusion

6 October 1993

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The unexpected discovery of "muon catalysis" occurred during the first of the 10-inch hydrogen bubble chamber experiments. As I mentioned in my earlier talk ("The Berkeley Programme"), our first physics priority was to observe the associated production of K^0 and Λ's and next to stop K^-'s in hydrogen to do with kaons what Panofsky had done with pions. The latter experiment separated kaons from the more abundant pions in the beam by dE/dx. Appropriate absorber was placed in front of the chamber to stop most of the kaons in the chamber thus allowing the pions to pass through with very low momentum.. We expected some of these slow π^-'s to decay in flight to μ^-'s that would subsequently come to rest in the hydrogen and decay to e^-'s and neutrinos. The first I heard of the peculiar sample of π-μ-decay-in-flight events was from Hugh Bradner. He, Luis Alvarez, and Don Gow were scanning this 10-inch film (with its small stereo angle) with the two views side by side so they could see these events in 3-D. They had observed about half a dozen events that had very nearly the same length of muon track where a variable path length was to be expected from decay in flight. It was because they were scanning in 3-D that they could tell the muon tracks were nearly the same length. In retrospect, if we had had the time to design and build our own magnet with a larger stereo angle, rather than using Wilson Powell's magnet with its non-optimal small stereo angle, we would not have been able to scan in 3-D and would not have observed this effect.

When these events were measured on our "Frankenstein" measuring machines, their length were all 1.7 cm. If, by some unknown process, π^-'s could decay at rest, their secondary μ^-'s would have a range of 1.0 cm. (normally, the stopping π^-'s "disappear" by one of the "Panofsky reactions."[1].) A muon with a range of 1.7 cm would have a kinetic energy of 5.4 MeV.

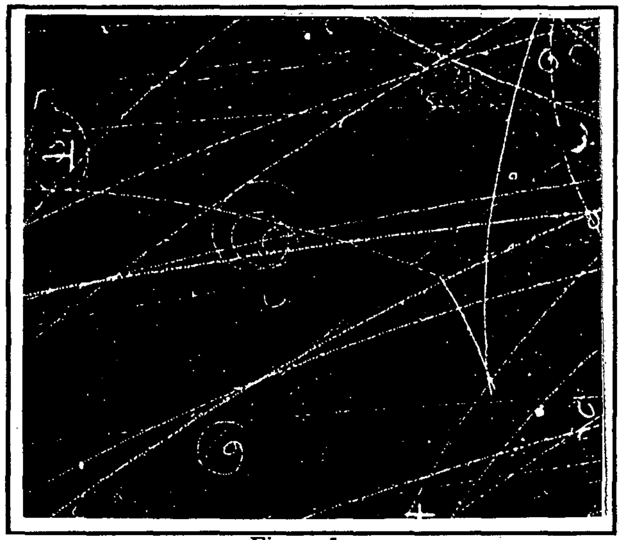

Figure 1

Then, a real surprise came. Some of these peculiar events showed a gap between the end of the primary track and the beginning of the second track. Figure 1 shows such an event where the tracks even over lap each other forming an X.

I remember trying to explain these gaps by inventing a new neutral particle. I got nowhere with it. The breakthrough came in an interesting way and it involved Marcello Cresti (one of the convenors of this conference) in a peripheral way. Just about the time Marcello joined us at Berkeley, a new coffee shop, the Cafe Mediteraneum, opened and began serving the first espresso in Berkeley. It was Marcello who introduced most of us to the delights of sipping espresso and talking physics. I can still remember my first cup. I tasted it for a week after.

As I recall, at "Cafe Med", late one Saturday evening Frank Crawford, Harold Ticho and his old University of Chicago schoolmate, Jack Crawford, an astrophysicist (who had joined the Astronomy Department at Berkeley), were discussing these puzzling events. Frank recalls giving up at midnight to get some desperately needed sleep. By 2 AM

Harold and Jack had the key to the puzzle. Jack, being an astrophysicist, remembered the figure 5.4 MeV as the energy released when a proton and a deuteron fuse to form He^3. They called Luie. The rest of us were called about 8 AM that Sunday morning. By about 10 AM we were all gathered in Edward Teller's living room, with most of us sitting cross legged on his beautiful oriental rug like Indians around their chief. We saw Edward at his absolute best as he struggled for about one hour with the complicated atomic and molecular physics. He talked aloud, mainly to himself, and finally came up with the following explanation of the puzzling gaps.

First, what we thought was an in-flight pion, was actually a stopping μ^- that ultimately formed a small μ-p atom (200 times smaller than a hydrogen atom). It diffused much like a thermal neutron through the liquid hydrogen (with about 10^{-3} of it deuterium) until it encountered a deuterium atom that has a 5% lower ground state energy (135 eV) (because of the reduced mass effect) than a hydrogen atom. When the muon was robbed from the proton by the deuteron, the new μ-d atom got some of this 135 eV and recoiled a millimeter or so (this explained the gaps!) and then formed a molecule with a hydrogen atom. We facetiously referred to these as "mulecules." The role of the muon was to bring the proton and deuteron 200 times closer together than in a normal p-d molecule, and thus to act as the catalyst of the p-d fusion. The muon got the bulk of the fusion energy via the Auger effect The muon then had a chance to repeat the process. Most often, however, it decayed. Figure 2 shows an example of the same muon producing two fusion's.

We announced our discovery[2] at the December 28, 1956 meeting of the American Physical Society at Monterey, California, just after The Physical Review received our paper. I remember clearly just prior to that time my first meeting with Lev Okun just outside our "bullpen" office. He told us that the Soviet theorists Zel'dovich, and (I believe he mentioned) Zakharov had already predicted the process. Lev may also have mentioned F. C. Frank.

You cannot imagine how excited we got when we realized that we had stumbled onto a possible unlimited energy source, that of tapping the oceans for the deuterium. We tried some quick experiments such as increasing the deuterium concentration. But it soon became clear to us that the inevitable

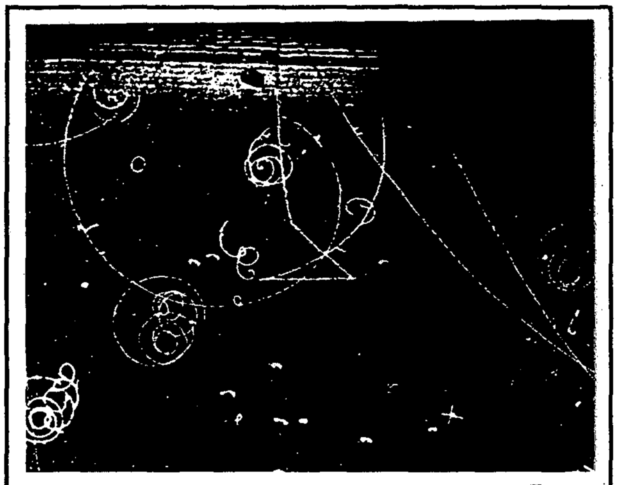

Figure 2

presence and build-up of He (that would gobble up and trap the muons until they decayed) would prove fatal to the sustained use of the muons. We dropped the "muon catalysis" work and quickly moved on to our particle physics experiments. The Chicago hydrogen bubble chamber group was far more aggressive and thorough than we were in studying this interesting phenomenon.

I remember for many years there was a physicist who would regularly visit Luie and give him status reports on the progress made by him and others toward the "muon catalysis" "break-even point.." When the TV announcement of "Cold Fusion" was made I tried to remember the name of that person so I could get his opinion of the experiments. That person was Steve Jones, the same one who was involved in the famous "Cold Fusion" controversy. The best summary of the current status of "Muon Catalysis" I have heard was at Steve Jones' talk[3] at the 1989 Baltimore Meeting of the American Physical Society, where two special evening sessions were set aside for "Cold Fusion" and Pons and Fleischman fail to show up.

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[1] Panofsky, Aamodt, and Hadley, Phys. Rev. 81, 565 (1951)

[2] L. W. Alvarez, H. Bradner, F. S. Crawford, J. A. Crawford, P. Falk-Vairant, M. L. Good, J. D. Gow, A. H. Rosenfeld, F. Solmitz, M. L. Stevenson, H. K. Ticho, and R. D. Tripp, Phys. Rev. 105, 1127 (1957)

[3] S.Jones, Bull. Am. Phys. Soc 34, 1228(1989)

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