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History of Bell Labs Physical Research, 1980–2006

Positron and Plasma Research

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Positron Research

As a prelude to positron research in the 1980's, Marv Leventhal came to Bell from Yale in 1968 and Allen Mills, Jr. from Brandeis in 1976, Brandeis then being the powerhouse of positron research due to the leadership of Steve Berko. Exploiting the good technology for which Bell was famous, Leventhal and collaborators C. J. MacCallum and A. C. Watts reported in Nature [1] the first evidence of red-shifted annihilation gamma rays from near the surface of the Crab Nebula pulsar using a balloon-born gamma-ray telescope. The measurements showed that the Crab-nebula neutron star had a mass approximately 1.4 times that of the sun.

In 1977-1978, Mills and Benjamin L. Brown set up the first positron beam at Murray Hill, and many seminal results followed. Initial experiments by Mills, Philip M. Platzman and Brown unraveled the mysteries of positronium and positron emission from single-crystal metal surfaces [2, 3]. The apparatus was moved to a larger room under the cafeteria where observations of thermal energy positronium (Ps) were made by Mills and Loren N. Pfeiffer [4] and details of positron-surface interactions were studied by Cherry Murray, Jack Rowe and Mills [5, 6]. The high-intensity beam from the new apparatus made it possible to observe the positronium negative ion in 1981 [7], it having been predicted by J. A. Wheeler in 1946 [8]. This was followed much later by the discovery of another of Wheeler's "poly-electrons," the di-positronium molecule, Ps2 [9].

In the technology area, Mills invented a seminal technique to enhance the brightness of positron beams (1980) [10]. This was followed in 1986 by the development of a high efficiency solid neon moderator to produce slow positrons [11]. This was used in subsequent decades as a much-improved source for trap-based positron beams.

In 1980, Steven Chu, Mills and J. L. Hall (JILA, Boulder, CO) began the first precise measurements of the 1S-2S interval in Ps, hoping to test quantum electrodynamics theory in an antimatter system. They reported their first measurements in 1984 [12].

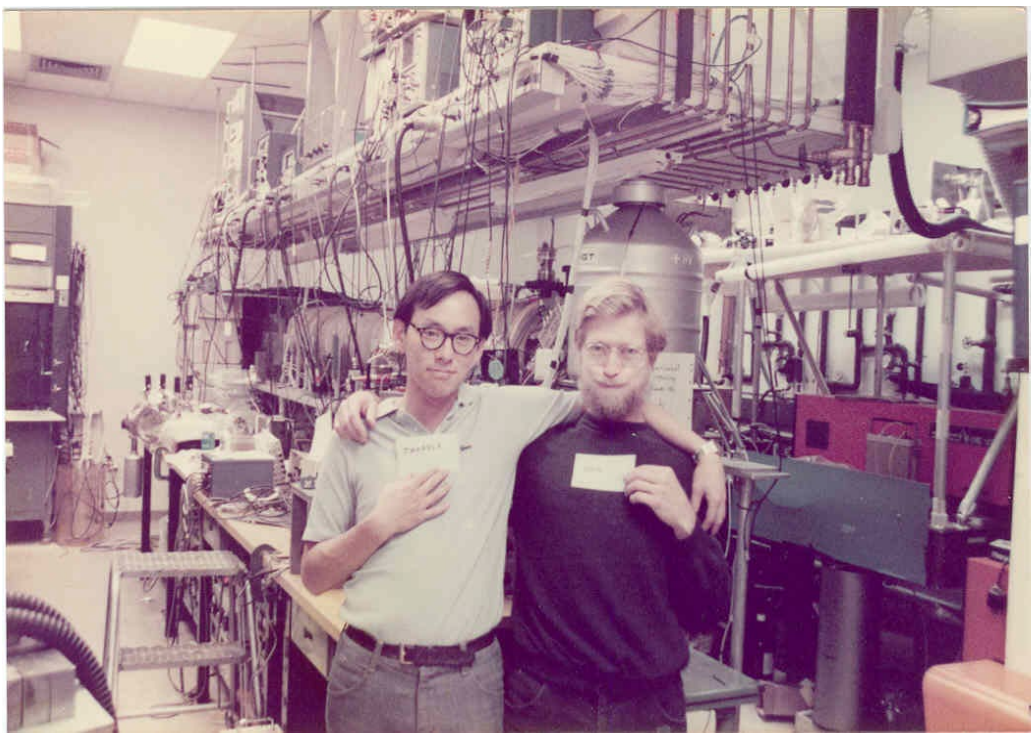
They then moved the experiment to a much larger underground laboratory in Building I at Murray Hill. There, they were able to exploit the intense, pulsed positron source (15 ms pulses of 105 positrons) that was developed by Earl Shaw, R. J. Chichester, and D. M. Zuckerman in conjunction with the microtron-based 20 MeV, free-electron laser (FEL) that they had built. However, to protect those working on the Ps experiment required additional shielding from the microtron beam dump and from a Dynamitron accelerator located on the other side of the experiment. This required a lead wall 8' high, 8" thick and 50' long comprised of 10,000 V-shaped lead bricks (25 pounds each). Mills got a quote from a vendor to build it and thought the price ($50,000 in 1986) way too high, so he and the team stacked the 90 tons of lead themselves! In the physics realm, using the new FEL positron source, Chu, Mills and Michael Fee reported a more precise measurement of the Ps interval in 1993 [13].

As described below, the new, larger room also housed the first device (1984–1988) for capturing and storing large numbers of slow positrons. It consisted of a three-stage trap using a buffer gas to slow and trap the positrons. The first physics result was the demonstration that positrons bind to molecules [14]. In 1988, Chu, Mills and collaborators made the first laser-excitation studies of muonium (i.e., the analog of their Ps spectroscopy) [15], and in 1994, Mills and Platzman discussed the possibilities to create a Bose-Einstein condensate of Ps atoms [16], a quest that continues today.

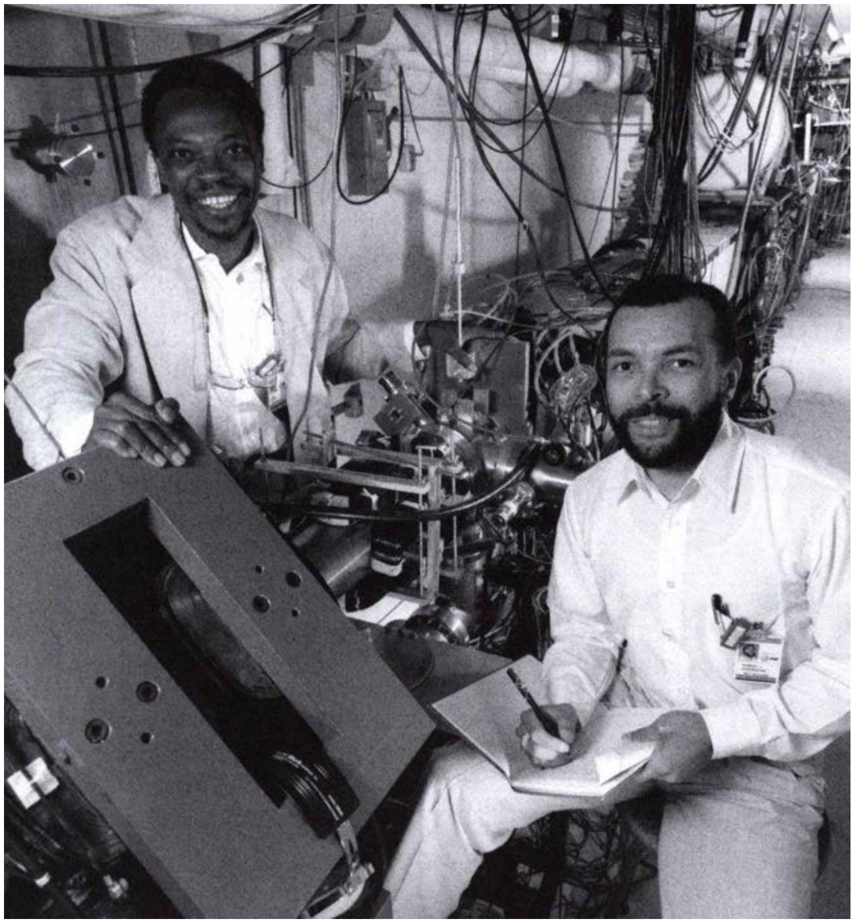
The positron work in the 80s and 90s spurred much science and technology. Mills' brightness-enhancement technique permitted much higher quality positron beams. The neon moderator turned out to be a nearly ideal source for trap-based positron beams, which continued to develop and are used worldwide for a variety of positron, Ps and antihydrogen experiments. Cassidy and Mills created the first di-positronium [9] and succeeded in making single-shot positron annihilation spectroscopy with a modified trapping apparatus [17].

Earl Shaw moved the FEL to Rutgers, Newark in the 1990s. The underground lab that housed it at Murray Hill was covered with earth. A small section of one of the odd-shaped lead bricks was painted gold, mounted on a stand, and given to Bill Brinkman as a memento of the wonderful research that had been done in that unusual lab.

Nagashima (Tokyo) [18] and Cassidy (London) [19] have made novel Ps beams with a subsequent generation of the Bell-Labs positron traps; and they are now used at CERN to create and study antihydrogen. The positron binding measurements motivated a systematic theory of positron-matter interactions that could treat virtual positronium formation, a long-sought goal in the positron community [20].



Steve Chu and Allen Mills in Building 1, room 6F002 (1982) with their first-generation Ps spectroscopy experiment. They hold signs “tweedle” and “dum,” no doubt to indicate their status as senior members of the technical staff.



Earl D. Shaw, at left, and Robert Chichester, with the microtron-based FEL that Mills and collaborators used as a source of pulsed positrons for their precision Ps spectroscopy experiments. From *Bell Labs News*, August 24, 1992, when the FEL was donated to the Rutgers University Newark campus. Courtesy of AT&T Archives and History Center.

Plasma Research

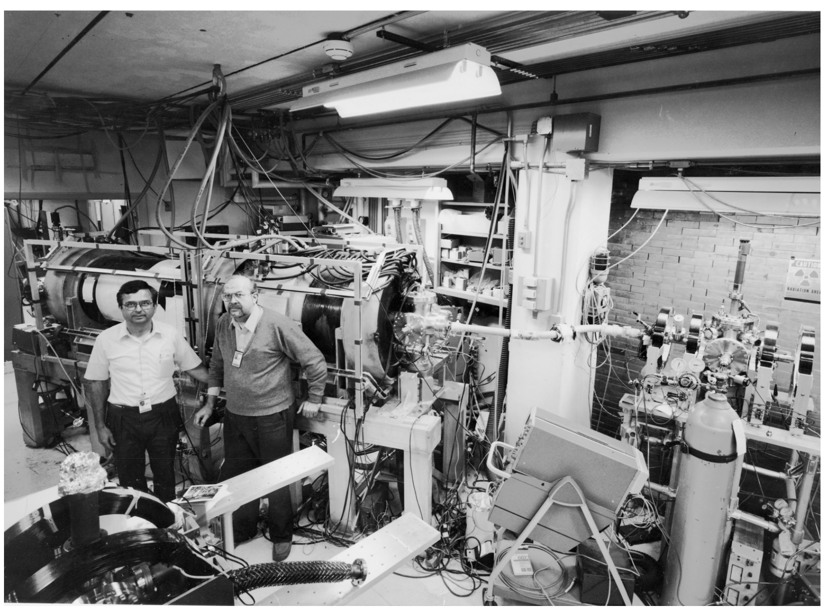
The landscape for plasmas at Bell in the 1980s was set by work that began much before then. The “plasmas” referred to here were known at Bell, even into the 80s, as “gas plasmas” to distinguish them from the solid-state plasmas which were the focus of much work in the 50’s and 60’s. Early “gas plasma” work includes theory by Phil Platzman and Sol Buchsbaum [21] and experiments by C. C. Grimes [22], W. M. Walsh [23], Raul Stern, and Jim Decker [24] often complemented by Platzman’s theoretical insights. Sol Buchsbaum’s outstanding theoretical work was “lost due to his management skills” in the later 1960’s (and later Vice President of Technological Systems in 1979).

In the 70’s, Dick Slusher and Cliff Surko developed a laser scattering technique to study waves and turbulence in plasmas [25], and Stern and Joe Johnson developed a laser-induced fluorescence (LIF) technique to study ion velocities [26]. Both techniques, particularly the LIF, would be used worldwide in the following decades.

Slusher and Surko's first laser scattering experiments on a small tokamak (a prototype fusion-plasma device) at Princeton (1975) [27] motivated Hasegawa and Kunioki Mima to discover a simple yet powerful nonlinear equation [28] to describe the plasma turbulence that the experimentalists discovered. The light scattering experiments continued on tokamaks at Princeton and other devices at MIT until the mid-1980s. Hasegawa's work with a string of brilliant post docs at Bell Labs led to many seminal works in plasma physics. He also pioneered advanced schemes for optical communications based upon solitary-wave physics concepts from the plasma community [29].

In a lunchtime conversation in the cafeteria at Murray Hill in 1983, Marv Leventhal and Cliff Surko mused about studying phenomena in tokamak plasmas using positrons as a test particle. Surko thought he could accumulate enough positrons to inject in bursts to get a usable signal to study light-particle transport (an important phenomenon about which little was known at the time), but he didn't know how to inject them into the plasma. Marv proposed making a positronium atom beam which could then be laser-ionized or be ionized by the hot plasma, and they decided to try the experiment. This required building a positron accumulator which they began shortly thereafter. To jump to the punchline, they never did the tokamak experiment, but the positron trap that they began to develop is now used worldwide.

They needed a pretty good-sized space to build the trap, and Allen Mills had such a space (discussed above), in the basement of Murray Hill, Building 1. It was being outfitted to begin the second-generation Ps spectroscopy measurements. In 1984, Marv and Cliff asked Allen if they could "borrow some space." They'd only need it for 18 months since they planned to put the trap on a tokamak at Princeton. Allen said "OK." (cf. Fig. 2) It stayed considerably longer (November 1988) thanks to Allen's generous cooperation ("humph, the trap is finally working – I can't kick them out!"), even after the Ps spectroscopy experiment beamline was being built (cf. Fig. 2) The trappers, Al Passner, Marv and Cliff, were able to trap positrons (3.3 x10^5 with a confinement time of 60 s) and make the first single-component positron plasma [30] before Surko left for UC San Diego in 1988.



Al Passner (right) and Cliff Surko with the buffer-gas positron trap in borrowed space in Allen's new and larger laboratory. The magnet coils and rails visible at the lower left are the start of the construction of the Chu-Mills beamline circa 1987.

Mills' plasma research at Bell in the '80s and '90s continues to impact science and technology. Stern and Johnson's laser-induced fluorescence technique became a standard tool to measure ion temperature in low temperature plasmas [31]. The Hasegawa-Mima equation has found wide utility in nonlinear and plasma physics. The success of the buffer-gas trap induced further work to tailor positron plasmas for various applications and is used worldwide [32].

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