Frank Calaprice

Frank Calaprice, professor of physics, has had a long and distinguished career in nuclear physics.

As a graduate student at the University of California-Berkeley from 1961–67, Frank joined the research group of Professor Eugene Commins who was studying the nuclear beta decay of ^{19}Ne, a short-lived isotope that could be polarized by atomic beam methods. He applied this method to ^{35}Ar and measured the magnetic dipole moment and the parity violating beta asymmetry of ^{35}Ar.

In 1964, Val Fitch and James Cronin at Princeton discovered CP violation in the weak decays of K-mesons. This discovery implied a violation of time reversal invariance in weak interactions and motivated the Berkeley group to search for a violation of time reversal violation in the beta decay of polarized ^{19}Ne. A first experiment was done observing in-flight decays of ^{19}Ne atoms in a polarized atomic beam. The result showed no evidence for a violation of T-invariance, but with modest sensitivity because of the short (msec) time-of-flight of the atoms past the detectors. Frank proposed a more sensitive experiment in which the decays of ^{19}Ne could be observed in atoms that were trapped in a cell for several seconds. This experiment was more sensitive and was successfully carried out at Berkeley. Again no violation of T-invariance was found.

In 1970, Frank applied for a faculty position at Princeton to continue research on time reversal invariance in nuclear beta decay. The research fit nicely with Princeton's new cyclotron, and also with the research of Donald Hamilton, who was doing atomic beam research. In addition, Hamilton had earlier written a number of papers on angular correlations of radiation emitted in nuclear decays. He knew very well the importance of the CP violation discovered by Fitch and Cronin, and knew what Will Happer had been doing on ^{19}Ne.

Frank continued research on time reversal invariance in the Princeton nuclear physics group under the leadership of Rubby Sherr and Gerry Garvey. The ^{19}Ne experiment continued with graduate students. Even with higher sensitivity there was no evidence for violation of T-invariance. The final results were the most sensitive test for T-invariance in nuclear beta decay for more than 20 years.

Other research included a search for second-class weak interactions, and a search for the axion particle proposed by Frank Wilczek and Steven Weinberg as a solution to the CP problem. No evidence was found for the initial axion hypothesis, but axions with a very low mass and weak interaction could not be ruled out.

When Happer and Gordon Cates joined Princeton's physics department, Frank and his colleague Art McDonald became interested in applying optical pumping methods to polarize rare gas atoms to search for parity violation in nuclear forces, and to search for T-violating electric dipole moments of rare gas atoms. Frank led a team of these physicists to search for the T-violating electric dipole moments of radon. This program resulted in the successful polarization and measurements of magnetic dipole moments of argon, xenon, and radon isotopes. The radon isotopes were produced at the ISOLDE isotope separator facility of the CERN laboratory in Switzerland. The optical pumping method was powerful and succeeded to polarize the radon nuclei, and allow NMR measurements of the magnetic dipole moments. However, at that time, the intensity of the source of radon isotopes was too weak to carry out a search for electric dipole moments, and the effort was stopped. Since that time, research on possible electric dipole moments of heavy atoms has continued by other groups. More intense sources of radon isotopes are also now available.

Starting in the 1990s, Frank played a leading role in the design, operation, and interpretation of data from the Borexino experiment, a scintillator detector designed to measure solar neutrinos—neutrinos emitted during the fusion cycles which fuel the sun. The Borexino solar neutrino detector is operating at Laboratori Nazionali del Gran Sasso in Italy and has been taking data on solar neutrinos since 2007. Borexino achieved a background of <30 counts/day/100 tons above 100 keV, the lowest ever reached in any solar neutrino experiment. It is not surprising that this phenomenal success in reducing backgrounds resulted in the observation, with a single detector, of the largest array of solar neutrino phenomena. Among the measurements achieved by Borexino are: the precision measurement of the ^{7}Be neutrinos from the *pp* cycle; the first measurement of *pep* neutrinos from the *pp* cycle; and the first real-time measurement of *pp* neutrinos, from the heart of the *pp* cycle. These observations confirmed the basic mechanism elucidated by Hans Bethe in 1939.

Throughout his two-decade involvement in Borexino, Frank was responsible for countless contributions to its construction and operation. The most significant contributions that can specifically be ascribed to him are the design and construction of the scintillator containment system, and the design, construction, and operation of the scintillator purification system. Frank also gets special credit for leading and fostering much of the scientific debate within the collaboration and for helping to shape the program in its final and very successful form, spearheading some of the most critical decisions taken by the collaboration on its global science strategy. As one example, the original design of the detector did not include the light and transparent set of nylon vessels which represents today the most critical piece of hardware of the scintillator containment system: Frank is credited with their invention and creation. As a second example, Frank personally pushed the collaboration towards the adoption of a purification scheme that would rely on the presence in the underground laboratory of a complete set of purification plants for the distillation, water extraction, and counter-current stripping with gaseous nitrogen of the scintillator. We know today that underground purification of the scintillator was crucial to the success of Borexino. The Borexino detector went on to perform a very detailed series of measurements on solar neutrinos. So far, it has produced the only real-time measurement of ^{7}Be neutrinos, the second-most abundant source of solar neutrinos; the first measurement of the high energy ^{8}B neutrinos with a scintillator; and the first ever measurement of pep solar neutrinos. The combination of results from the Borexino and KamLAND experiments has provided solid evidence for geoneutrinos—neutrinos emitted by the decay of radioactive elements in the Earth's crust. Finally, the collaboration has recently completed a paper detailing the first real-time measurement of *pp* neutrinos, the most abundant source of solar neutrinos.

Frank is widely recognized as one of the few authorities in the field of very low-background, low-counting rate experiments. More recently, Frank played a crucial role in the start of two dark matter searches: the DarkSide program for searches with underground argon and the SABRE program for searches with sodium iodide detectors in an active anti-coincidence veto. Frank's contributions were crucial to establish the technology of DarkSide, a liquid argon time projection chamber, as a credible candidate for large-scale dark matter searches. Drawing on his expertise in nuclear physics and on organic liquid scintillator, he proposed, designed, and developed the most efficient veto detector for dark matter experiments, based on an organic liquid scintillator heavily doped in boron. Thanks to the success of its veto, DarkSide-50 is the only experiment operating with zero background in the search for dark matter with mass above 50 GeV/c^2 and has the best exclusion limits for the search of dark matter with mass below 8 GeV/c^2. Frank is now deeply involved in developing the SABRE program to verify the only claim for detection of dark matter stemming from the results of the DAMA/LIBRA program, and is leading a very promising effort to develop sodium iodide detectors with the ultra-low radioactive background.

Frank is a dedicated teacher and inspiring mentor. Between 1996 and 2012, he guided six Princeton graduate students' Ph.D. dissertations on the Borexino Solar Neutrino Experiment and mentored six postdoctoral students. Frank has fostered talent and offered opportunities, physics insight, and career advice to a diverse group of students, one of whom said, "All the nuclear physics I know I picked up over the years from him." Most of Frank's doctoral students and postdocs have continued to successful careers in physics, with faculty positions or prestigious fellowships (depending on seniority) and high visibility in the areas of astroparticle physics and gravitational wave detectors.