70 years of Nuclear Physics at ND

(1937 – 2007: seventy years of Nuclear Physics at Notre Dame)

Nuclear Physics was born at the University of Notre Dame in 1937 with the first successful experiments accelerating particles. These experiments began an active scientific program and laid the foundation for one of the oldest nuclear laboratories in the country. During its 70 years of history, the Nuclear Laboratory has contributed significantly to all aspects of Nuclear Physics, to our understanding of the nucleus as a unique few body quantum system, to our interpretation of nuclear reactions and reaction mechanisms as signatures of the four fundamental forces governing the Cosmos, and finally to the critical role these reactions provide for the synthesis of the chemical elements formed in generations of stars since the beginning of our Universe.

The first nuclear accelerator was designed, constructed, and built in 1936 in Cushing Hall from University funds by Jose Caparo of the department of Electrical Engineering and George Collins from the department of Physics at Notre Dame. The accelerator provided a new tool for scientific research on the subatomic particle level and brought immediate recognition of the University as a new emerging center for scientific research. In the late 1930's, members of the laboratory presented the first experimental proof for the existence of Cerenkov radiation which had been predicted but never previously observed, performed the first photodisintegration studies of nuclei such as deuterium and beryllium, and demonstrated reaction phenomena such as Mott scattering and the production of Bremsstrahlung with accelerated electron beams.

These successes motivated the University to grant funds for a second accelerator, which was designed to reach 8 Million Volts. It was at that time the largest machine ever constructed. The accelerator was located in the basement of the old Science Building, today's La Fortune Center. This second Notre Dame accelerator was completed in early 1942. The completion coincided with the US entry into the Second World War and the accelerator was immediately drafted for the Manhattan project, putting fundamental research on hold. The Manhattan Project co-opted a number of laboratories with state of the art equipment around the United States in order to guide experimentation that would aid in the development of a nuclear bomb. Research for the Manhattan project consisted primarily of determining the effects of intense radiation on materials and on the possibility of radiation induced chemical reactions. This was done in utmost secrecy, illustrated by the fact that the logbooks during this time were not made "public" until well after WWII and contained no figures or technical drawings from 1942 to 1945. Even after the war, Notre Dame's involvement with the development of the bomb was not immediately made public until all that information was declassified in the 1980's.

After the war in 1946, the accelerator returned to peace time research on fundamental nuclear structure and was mainly used to study the interaction processes of up to 4MeV electrons with matter. The old Science building soon proved to be too small for the rapidly growing Departments of Physics and Chemistry. A new building, Nieuwland Science Hall was completed in 1953. The old accelerator was not moved into the new building, but members of the Physics Department, Walt Miller and Bernie Waldman constructed a new, 4 million Volt accelerator for continuing the electron beam research program at the new location. This was supported through a grant of $35,000 from the Atomic Energy Commission (AEC). This third accelerator was the first to be used for a rapidly evolving training and research program for the growing PhD program at the Department of Physics which had 15 graduate students in nuclear physics in 1955. This 4 MV accelerator was the core of an active nuclear physics research program at Notre Dame for more than 10 years and it was mainly supported through funds from the Office of Naval Research (ONR).

Other areas of research also flourished at the Nuclear Laboratory. For example, in 1954, John Mihelich joined the faculty at Notre Dame coming from Brookhaven National Laboratory to start a new area of research in beta- and gamma-ray spectroscopy. The group of Profs. Mihelich and later Funk (1958) produced some of the present leaders in the nuclear spectroscopy and structure community. This program concentrated on nuclei in the rare-earth region and primarily utilized the newest techniques of the day in using scintillation and solid-state detectors for Gamma-ray spectroscopy, as well as, permanent magnetic spectrographs to measure internal conversion electrons with high resolution. It was funded by the AEC and involved a major collaboration with Oak Ridge National Laboratory. Shortly thereafter, Cornelius Browne from MIT joined the nuclear faculty and started a research program using light ion beams and particle spectroscopy. He constructed a large Brown-Buechner spectrograph for the momentum analysis of reaction products to explore the details of nuclear structure and nuclear reaction mechanisms. In 1957, Sperry (Bud) Darden from the University of Wisconsin joined the accelerator group for doing research on nuclear reactions. Prof. Darden later specialized in reaction studies with polarized ions. In 1958, Emerson Funk, from the University of Michigan, became a member of John Mihelich's group and the further extended the nuclear spectroscopy research program by adding gamma-gamma directional correlations and short lifetime measurements. The use of high resolution Ge(Li) detectors, the first at a Midwest university, provided an enormous boost to the gamma-ray program. All of these high resolution particle and gamma detection techniques provide the backbone of Nuclear Physics research worldwide. Paul Chagnon from the University of Michigan joined the accelerator group in 1962, starting a program centered on nuclear spectroscopy studies using particle-gamma angular correlations and lifetime measurements.

In the early 1960's a proposal was made by the nuclear physics faculty first to ONR and subsequently to the National Science Foundation (NSF) for the construction of a new Tandem accelerator. The proposal was funded at a level of $2.5 million in December 1965, the largest research grant Notre Dame had ever received at the time. The new accelerator and the target halls for the planned research program required the construction of a new building which was added to the back of Nieuwland Science Hall. The construction started in 1966 and the building was completed in 1967 with the accelerator being moved in by railroad in 1968.

In 1968, the nuclear physics group had consolidated into a group of six faculty members using the accelerator facilities. After Walt Miller had become chair of Physics and slowed down in research, Cornelius Browne became the Principal Investigator for the NSF grant. The most exciting facility at the laboratory was the newly developed second generation Browne-Buechner Spectrograph. Parallel to that, a polarized beam program was developed centered around the newly purchased polarized ion source from the University of Wisconsin. This program ended with the retirement of Bud Darden as the last man who could operate the complexities of that source. The gamma spectroscopy program, at times one of the leading in the country, emerged from the close collaboration between Mihelich and Funk who had started to build an in-beam spectroscopy program at the new machine.

After the retirement of Walt Miller, two new faculty, Jim Kolata and Umesh Garg joined the nuclear group. Kolata built a strong heavy ion beam research program focusing mainly on sub-Coulomb barrier fusion at low energies. Umesh Garg developed a program involving giant resonances and also collaborated with Mihelich and Funk on spectroscopic studies and recoil-distance method lifetime measurements involving heavier nuclei. Garg collaborated with Argonne National Laboratory in the development of a new complex gamma detector array, the Notre Dame Argonne Ball, which opened new horizons in gamma spectroscopy, namely in the study of fast rotational modes of nuclear excitation. This strengthening of the nuclear physics faculty proved to be very timely. In the early 1980ies the NSF seriously considered closing the laboratory due to a drastic overall reduction of government sponsored research funding for nuclear physics. The addition of two new faculty members (Kolata and Garg) which brought innovative research programs to Notre Dame allowed NSF to carefully reconsider the strong Notre Dame program, and the Nuclear Structure Laboratory (NSL) remained fully funded.

In 1986, Michael Wiescher joined the faculty and developed a new branch of Nuclear Physics at the laboratory, Nuclear Astrophysics. This program focused at first on the use of the FN tandem accelerator developing new indirect techniques to study nuclear structure effects which could provide signatures for the understanding of stellar explosions such as in supernovae or of cataclysmic binary systems as novae and X-ray bursts. In 1989, with the retirement of John Mihelich, Ani Aprahamian joined the laboratory, adding a new dimension in nuclear structure physics by developing a new program at the laboratory studying the degrees of freedom for dynamics of nuclei with regards to vibrations and rotations using gamma-ray spectroscopy techniques.

In 1993 the old 4MV accelerator was replaced after nearly forty years of service by a low energy 3.5MV KN Van de Graaff (VdG) from Queens University, the fifth in the long succession of Notre Dame accelerators. This machine generated additional independent NSF funding for the development of a low energy program in nuclear astrophysics to complement the continuing activities at the FN tandem. With this upgrade the nuclear astrophysics program at Notre Dame became one of the most successful programs in the country and lead to the founding of a Physics Frontier Center at the University of Notre Dame in Nuclear Astrophysics (In collaboration with MSU, ANL, and the U Chicago)

The experiments at the low energy accelerators were geared towards the direct simulation of nuclear processes driving stellar evolution.

In 1994, Cornelius Browne retired after nearly 30 years as Principal Investigator and Director of the Nuclear Structure Laboratory to be replaced by Jim Kolata. He had steered the laboratory through one of its most successful but also most difficult periods of its history. His last challenge came with the beginning of the last decade of the century. In 1990 the NSF had decided to phase out most of the country's small university operated tandem laboratories since lack of funding and government support had made it impossible to maintain and operate these labs any longer. From fourteen NSF supported accelerator laboratories, including facilities at CalTech, Princeton, and Wisconsin, only four were to continue. On the basis of this review the Notre Dame Nuclear Structure Laboratory was selected as one of the four midsize research accelerator laboratories in the country to be continued. That decision was mainly based on the success of the new directions the laboratory had chosen in radioactive beam physics and nuclear astrophysics.

Jim Kolata, in close collaboration with Fred Becchetti from the University of Michigan, has designed and built the first successful radioactive ion beam facility, TwinSol, in the country and developed a strong program with light radioactive beams in nuclear reaction physics, nuclear structure physics, and nuclear astrophysics. For nearly a decade this program was leading the newly emerging field of radioactive beam physics. Only in the first years of the twenty-first century have radioactive beam programs at Oak Ridge National Laboratory, Argonne National Laboratory, and TRIUMF, Canada become competitive. The NSF funded the design and construction of TwinSol with $350,000. To provide more stable and higher energies for the primary beams the Tandem was upgraded to 11 MV terminal voltage through funding by the Notre Dame Graduate School. In addition the traditional belt charging system was replaced by a Pelletron chain system in the middle nineties. This improved operation and reliability of the machine enormously. In 1994 Ed Berners retired. For thirty years he had maintained the successful operation of both the 4MV and the FN tandem accelerators at Notre Dame. He was replaced by Dr. Larry Lamm who had graduated from the Notre Dame PhD program in 1989.

A new faculty member Alejandro Garcia joined the group in 1994 to build a program in accelerator based weak interaction physics. This program ran experiments using the FN tandem accelerator and added substantially to the visibility and to the broad spectrum of nuclear physics activities at the laboratory. Garcia decided in 2002 to follow an offer to join the faculty at the University of Washington.

With the end of the very successful funding period of 1988-2001, Jim Kolata resigned as Principal Investigator and he was replaced by Ani Aprahamian as the new Director of the Nuclear Laboratory. In view of these new developments, the NSF suggested the merger of the two independent nuclear physics grants into one. The new grant brought a significant increase in funding which allowed faculty to purchase new detectors and electronics to bring the laboratory up to the technological level necessary for a modern research laboratory. In addition, the university agreed to a major renovation of the laboratory – for the first time in nearly forty years. Significant funds were provided allowing new meeting and shop facilities as well as a general facelift of one of the oldest and most successful research facilities of the university.

The Nuclear Astrophysics program was further strengthened in 2000 with the acquisition of a third accelerator, a 1MV Van de Graaff machine from the University of Toronto. Similar to the acquisition of the KN Van de Graaff from Queens, this machine was brought on University funding from Canada to Notre Dame and was completely rebuilt by graduate students and postdoctoral researchers, converting it to an entirely computer controlled, high intensity accelerator.

In 2000 the Nuclear Astrophysics program at Notre Dame joined forces with astrophysics groups at Michigan State University and the University of Chicago to form the Joint Institute for Nuclear Astrophysics, JINA. While this institute was initially only supported with small funds from the NSF to develop a conference and visitor program, in 2003 JINA was awarded a $10 Million NSF Grant for five years as a Physics Frontier Center in Nuclear Astrophysics. That was the highest NSF award Notre Dame ever received at that time. While the main purpose of JINA is the development of a strong inter-institutional research program in Nuclear Astrophysics, a substantial fraction of the funding is also allocated for improving the experimental conditions and for developing novel experimental techniques in this field. Part of this program is the development of a next generation recoil separator for low energy experiments in inverse kinematics. In its first three years of funding the JINA program has rapidly expanded in terms of its scientific program and in number of its member institutions. Today JINA provides national leadership in the field with many university and national groups participating in a global research effort.

TwinSol remains one of the key research instruments of the laboratory. Jim Kolata continued and broadened his program in low energy radioactive beam physics; Ani Aprahamian developed a new program in gamma spectroscopy with radioactive ^{6}He beams, and Michael Wiescher used TwinSol not as a radioactive beam facility but as a large-acceptance momentum separator for astrophysics related experiments.

The Browne-Buechner spectrograph had been sitting idle since 1998, when in 2003 a new faculty member, Philippe Collon, began work on a renovation converting it successfully to a gas-filled spectrometer for a new program in accelerator mass spectroscopy at the FN tandem accelerator. This initiative, together with the development of a PIXE material analysis program, will develop the laboratory's capability for a large number of applications for nuclear physics based analysis techniques in the fields of nuclear astrophysics, anthropology, archaeometry, and oceanography.

Last year, in 2006, Xiadong Tang joined the nuclear physics group as a new faculty member, bringing the group up to its original strength of six teaching and research faculty in Nuclear Physics. His research focuses on the development of new experimental techniques and methods in Nuclear Astrophysics. The same year Ani Aprahamian went to the National Science Foundation as a program director for Particle and Nuclear

Astrophysics. Michael Wiescher became the Principal Investigator and Director of the Laboratory starting in August of 2006.

The Nuclear Science Laboratory, NSL, has been in operation for over seventy years and it is presently in the forefront of Nuclear Physics in the world. During the last forty years the laboratory generated a total funding of approximately $35 million for the university, not including the JINA funds. The nuclear physics group today is one of the most productive groups in the country. It has granted approximately 180 PhD since the implementation of the Graduate Program at the Department of Physics in 1938. The activity and quality of the research program can be measured by the large number of nearly 1000 peer reviewed scientific publications produced over seventy years of research. With presently six teaching and research faculty members, four research faculty, four postdoctoral fellows, three staff members, and twenty two graduate students the group today provides an extremely vigorous and active research environment. With the next funding period coming up in 2008, the Nuclear Structure Laboratory looks forward to continuing into the future its long and active research program.