Spotlight

The Winding Path

By: Stephen Cohn, '85

Maryland Physics as an undergraduate was great! It was hard and fun at the time, but also a great foundation to build on. The department then (and now) has such a good reputation that I could choose among some of the top graduate schools. One school I visited was MIT. There the physics Department was in a dark foreboding corridor. I wanted to get a look at Cambridge and Boston so I went to the top of the tallest building on campus to get a view of the city. This turned out to house the Center for Meteorology and Physical Oceanography. Some of the grad students invited me to look out their window, and we got to talking. That fortuitous view started me on the path to a Ph.D. in Atmospheric Science. Hey, a lot of meteorology is fluid dynamics and that's PHYSICS, right? My graduate research at MIT took me into the world of Doppler radar, both to observe the Ionosphere and also much lower in the atmosphere. The first boundary layer (lowest few km above the surface) wind profiling radars were being developed then. These use Bragg scatter to bounce energy from refractive index gradients (caused by turbulence and variations in water vapor, pressure, and temperature). The great thing about these radars is that they can measure the wind above the ground even in "clear air". The weather radars we see on the TV news need rain or snow to scatter energy, but Bragg scatter doesn't - so they greatly expand options for measuring atmospheric phenomena. Today the U.S. and several other countries operate networks of wind profilers.

Next stop was a post-doctoral job at McGill University. There the Department of Atmospheric and Oceanic Sciences was just getting a boundary layer radar, so it was a natural fit. McGill has an impressive reputation too, in many fields. There were two great aspects of the two years I spent there. The first was working with Prof. Roddy Rogers. He's a very nice guy, and he also wrote the book on cloud physics - literally ("A Short Course in Cloud Physics"). Cloud physics has aspects of thermodynamics, fluid dynamics, molecular physics, and just plain dynamics. Incidentally, I had met Prof. Rogers at a radar meteorology conference in Paris. He had a poster presentation next to mine, so we had a chance to talk a lot. I suspect that chance meeting had a lot to do with my getting chosen for this post-doc. The second great part of McGill was its location - downtown Montreal, Canada. Montreal has an unbelievable mix of cultures. The dominant French Canadian culture makes it like living in Europe (but only a 12 hour drive from MD), but the western part of the island of Montreal is more English. There are also many, many other cultures and recent immigrant groups. In summer there is a festival just about every weekend (Jazz, Caribbean, Comedy, etc.), the suburbs are great for cycling, the Laurentian Mountains are an hour away, and the community is friendly. Then again, after two Canadian

Spotlight

How Strange is the Proton "Sea"

By: Professor Philip Roos

In the four decades since I began research in nuclear physics, I have observed, and participated in, great changes in the field. Nuclear physics is still the study of the strong interaction between the fundamental constituents of matter, and how they combine to make the nuclei of the atoms. However, the size and focus of the research effort has changed enormously. When I first arrived at Maryland after completing my Ph.D. in the mid-sixties our field was strongly focused on understanding the properties of nuclei - their size, shape, decays, energy levels, nuclear wave functions, etc. Also there was a strong emphasis on theoretical treatment of nuclear reaction dynamics, since much of the information about nuclei was resulting from the nuclear reaction studies taking place at the numerous accelerators around the U.S. Our understanding of nuclei and nuclear reactions was primarily based on phenomenological treatments of the nucleon-nucleon interaction based largely on meson exchange models; e.g., the two nucleons interact strongly by exchanging a meson, such as a pi-meson. At that time there were approximately 80 particle accelerator laboratories in U.S. universities and national laboratories, mostly small accelerators, and a typical experiment might involve 3 to 5 physicists and run continuously for a few days.

Around that same time and well into the 70's and 80's, particle physics research studies of high energy reactions identified a myriad of new particles and indicated the presence of pointlike particles in our "fundamental" nucleons. The combination of experiments and theoretical insight and progress has led to our current understanding of hadronic (nucleons and mesons) structure as made up of pointlike particles called quarks, of which there are six types, or flavors. The strong interaction between these hadrons arises from the exchange of quanta of energy called gluons. The fundamental theory which describes the interaction of quarks and gluons is called Quantum Chromodynamics (QCD). The strong force, as described by QCD, is complicated and not amenable to simple solutions. In fact there is currently only one approach that would seem to provide a method for solving problems, such as the internal structure of a nucleon, although the available computational power is still insufficient to obtain a realistic solution. For this reason our knowledge of the internal structure of the nucleon or other hadrons comes primarily from the interpretation of experimental results.

These theoretical developments, technological advancements, and the costs of doing experimental science have led to a concentration of research at a few accelerator laboratories. Currently there are approximately 7 nuclear physics laboratories in the US, and only two of these are major facilities. Consistent with this, the scale of the experimental effort has increased enormously, in terms of manpower, time, and costs. A typical nuclear physics experiment at one of the major facilities today would involve 50 or more physicists, run continuously for several months, and cost well into the millions of dollars - all in the name of progress.

With these changes there has also been a broadening of the nuclear physics community in terms of their research interests. Some nuclear physicists have continued to study the properties of nuclei, pushing to the limits of stability, in terms of the proton or neutron excess, as well as the limits of angular momentum and deformation. Others have chosen to venture into relativistic heavy ion collisions at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven in search of matter that would have been present in the very early universe. Still others, such as members our experimental group at Maryland, have chosen to focus on understanding the structure and interaction of hadrons in terms of their quark and gluon degrees of freedom, and to understand QCD in the regime relevant to nuclear physics, a regime in which the strong interaction cannot be treated perturbatively.

One of the two major U.S. nuclear physics facilities at which QCD related research takes place is the Thomas Jefferson National Accelerator Facility in Newport News, VA. The CEBAF accelerator at Jefferson Laboratory currently can deliver electron beams in excess of 100 microamperes (~6x10^14 electrons/ second) to three experimental halls with energies up to 6 GeV. These electrons have a deBroglie wavelength of 0.2 fm
(2 x10^-16 m) allowing experiments to probe structure down to a small fraction of the size of the nucleon. (Currently a proposal has been submitted to the DoE to double the energy of the accelerator to 12 GeV which would then permit extensive searches for new particles which, if discovered, will lead to a further understanding of QCD).

The University of Maryland Experimental Nuclear Physics Group has focused their efforts over the past decade at the Jefferson Lab and much of the research has been focused on understanding the structure of the nucleon. We have participated in scattering studies to measure the electric and magnetic structure of the nucleon - particularly the electric form factor of the proton and neutron (Professors Kelly and Chang and Ph.D. student Nikolai Savvinov have played important roles in this work). Such measurements determine the charge density and magnetization density of the proton, but do not provide explicit information on the quarks and gluons that comprise the nucleon.

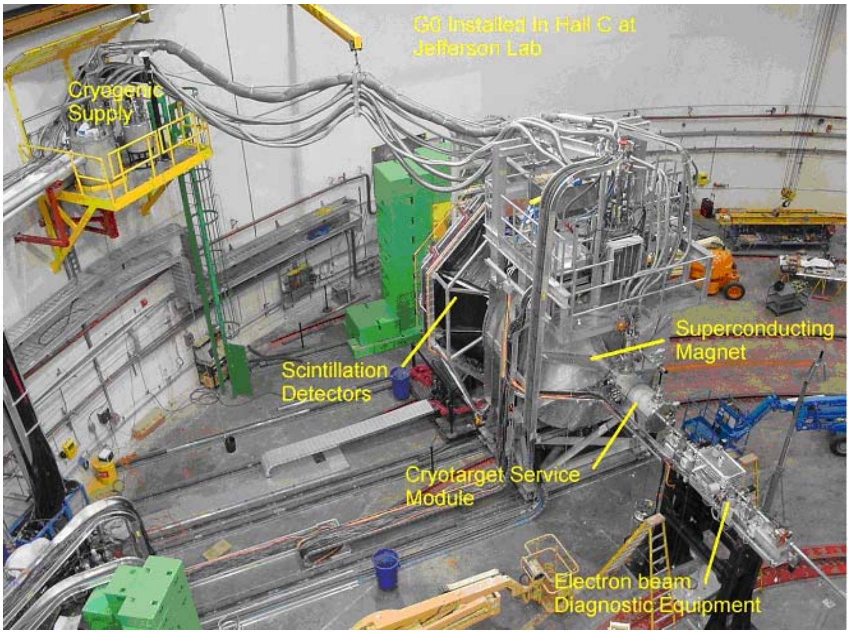
Important to furthering our understanding of QCD is the understanding of the underlying structure of the proton. In the simplest QCD based theoretical model the nucleons consist of three quarks, referred to as valence quarks, and only the up and down flavors of quarks (the lightest of the six quarks) are present. For example, in this simple model the proton would consist of two up quarks and one down quark, and the neutron as two down and one up quark. Such a simple model had some remarkable predictive successes (spin of the nucleon, magnetic moment), but we know that it cannot be correct. For example, from many years of studying the proton, we know that there is a pi-meson (pi-mesons consist of a quark-antiquark pair) cloud around the nucleon which indicates that there must be significant 4 quark-1 antiquark components in the nucleon ground state wave function. The additional quark-antiquark pairs are referred to as "sea" quarks. Also in recent years measurements with polarized leptons (mu-mesons and electrons) have shown that the spin of the nucleon is not due to the three valence nucleons - perhaps less than 25% arises from that component of the ground state wave function. This work led to speculation that the nucleon may well have significant components from other quark flavors, and since the next lightest quark is the strange quark, one might expect significant strange quark-anti strange quark pairs present in the ground state. (Note that we must have the quark-anti quark pairing so that the proton ground state has no strangeness - an empirical fact.)

The determination of the strange quark content of the nucleon ground state is the goal of a major experimental effort by members of our group. The so-called G0 experiment at Jefferson Lab utilizes the weak interaction to learn about how strange quarks contribute to the proton's charge and magnetism. Professors Betsy Beise, Research Scientist Herbert Breuer, graduate student Jianglai Liu, and I, as Deputy Spokesman, have been playing major roles in this G0 experiment. Additionally, over the past four years during the construction phase, approximately 9 University of Maryland undergraduate students have made contributions to this research effort. Shown in the picture are Ken Rossato and Kristen Kiriluk who worked this summer on the detector support structure. The wooden "box" is a prototype Cerenkov detector that they constructed to check the design of the support system.

The G0 experiment will measure the parity-violating asymmetry in elastic electron-nucleon scattering for a range of scattering angles or momentum transfers. Specifically, we will measure the difference in the elastic scattering of positive helicity electrons (spin of electron aligned with its velocity) and negative helicity electrons (anti-aligned), the difference arising from parity violation due to the weak interaction. These asymmetries are sensitive to the interference of the weak and electromagnetic amplitudes. From the measured asymmetries, therefore, the weak form factors of the nucleons can be determined. The vector weak form factors, electric and magnetic, are analogs of the familiar charge and magnetic elastic form factors of the nucleons. By measuring the asymmetry for both forward and backward scattering angles the G0 experiment will be able to separate the electric and magnetic form factors. Furthermore, by measuring a range of momentum transfers, information will be available on the spatial distribution in the nucleon.

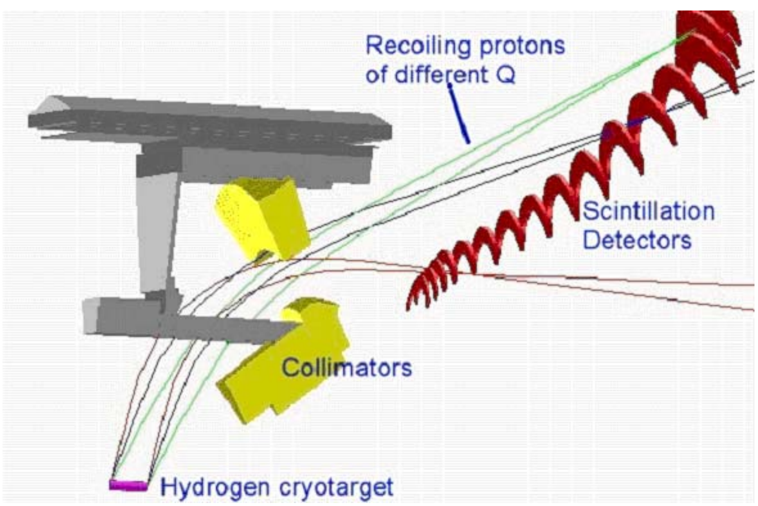
Once these data are obtained the G0 data will be combined with earlier data for elastic scattering to compare the electromagnetic and neutral weak vector form factors. This will permit one to extract the contributions of each of the three main quark flavors present in the nucleon: u, d and s. The direct relation between the sets of form factors is possible because in the Standard Model the couplings of photons and Z's to the quarks are precisely known (the electromagnetic and neutral weak charges, respectively). As noted above, by measuring asymmetries at both forward and backward scattering angles, the contributions of each quark flavor to the charge and magnetic form factors can be determined.

The difficulty of the experiment, and the reason for the large investment of manpower and money, is due to the fact that the asymmetries are a few parts per million. The proposed accuracy of the G0 experiment is a few parts in 10^7. Clearly, based on counting statistics alone, such a experiment necessitates the measurement of something of the order of 10^14 elastic scattering counts. A typical experiment at Jefferson Lab might take data at a rate of a few to ten kHz, so any attempt to carry out the experiment using the conventional equipment would take far too much time. Therefore to carry out the G0 experiment, dedicated equipment had to be constructed. A picture of the G0 experiment installed in Hall C at Jefferson Lab is shown in the picture.



The heart of the experiment is a magnetic spectrometer consisting of an eight sector superconducting toroidal magnet. This magnet will focus recoil protons (forward angle scattered electron measurement) or electrons (backward measurement) from a 20 cm long liquid hydrogen or deuterium target to pairs of plastic scintillator detectors.

The picture below shows a side view of theG0 equipment and a "cartoon" which indicates how the system works in detecting the recoil protons.



The effect of the magnetic spectrometer is to increase the solid angle or acceptance and to reduce the unwanted background particles from reaching the scintillators. At the design goal the scintillators will be counting elastic recoil protons at rates of 500 kHz to 1 MHz, so that for a given momentum transfer (defined by each specific scintillator) we have an overall rate of 4-8 MHz. This permits the experiment to be carried out (at least from the standpoint of counting statistics) in roughly two months. For the forward angle measurements, time-of-flight will be used to separate elastic protons from background using a pulsed 40 microampere beam current (31.25 MHz rather than the standard 499 MHz from the CEBAF accelerator). At these high counting rates, it was necessary to design and build custom time digitization electronics. In the backward experiment, the pairs of scintillators are spatially separated to allow momentum and angle measurement. The range of momentum transfers accessible with this apparatus is from about 0.1 to 1 (Ge v/c)^2.

The G0 experiment is certainly the largest experiment in which I have been involved during my 40 year career. The experiment is a collaboration of approximately 85 physicists from Caltech, Carnegie Mellon, Connecticut, Illinois, IPN-Orsay, ISN-Grenoble, Jefferson Lab, Kentucky, Louisiana Tech, Manitoba, Massachusetts, Maryland, New Mexico State, Norfolk State, Northern British Columbia, TRIUMF, Virginia Polytech, William & Mary, and Yerevan. The cost of the experiment, excluding the salaries of the physicists and technicians involved, is approximately $6.5M, provided by the National Science Foundation and the Department of Energy. At this time all of the equipment has been constructed and tested, and the first shake down run was carried out at the end of 2002. All systems are "Go", and the data production phase for the forward angle measurements will occur early next year. Following this the whole system will be rotated 180 degrees, and the backangle measurements begin. The tentative schedule call for these measurements to be made in the 2005-2006 time frame. That is why I refer to the G0 experiment as my retirement experiment.
More information regarding the technical elements of the experiment can be found on the experiment web page http://www.npl.uiuc.edu/exp/G0/G0Main.html.

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winters I was ready to move south again.

This time it was to Boulder, Colorado and the National Center for Atmospheric Research (NCAR). Finding that job was also serendipity. I made a trip to Boulder to meet with the group at NOAA who had pioneered wind profilers, but also stopped in at NCAR to visit a colleague I knew from a workshop. It turned out he was leaving NCAR to return to his home in Belgium. His departure created a job opening, and I was hired a few months later. That move was almost 10 years ago and I'm still there. At NCAR I'm a scientist in the Atmospheric Technology Division, and still work with wind profilers, but also with other radars, lidars, and other instruments. Over the years we've improved the capabilities, and developed measurement and signal processing techniques that have increased the time and space resolution of these instruments. This makes them more powerful tools to study atmospheric phenomena. My group also collects data in support of many research projects. Using wind profilers in conjunction with many other measurement devices, we've studied Lake Effect snowstorms, atmospheric gravity waves, temperature inversions that can trap pollution close to the surface for many days, modification of storms passing over mountain chains, and so many other topics. Most recently, I've been the lead scientist on a project to develop a safety system to warn airplanes of turbulence and wind shear near the Juneau Alaska airport.

So at NCAR it's been a mix of science and engineering, and always with an emphasis on studying problems that affect our lives. Ultimately, I think that's one reason I choose meteorology over a more fundamental area of physics - there are so many opportunities to have an immediate impact on people's lives.

Boulder is also a great place to live. I met my wife Jennifer here and we now have a 3-year old daughter and a new baby boy born this September. It's been 18 years(!) since I got that B.S. at UM Physics. Its served me well - especially the hands-on laboratory exercises. Hey, do you guys still use Bevington's book on Data Analysis techniques? I do.

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