E00-006

The G0 Experiment:
Measurement of the Neutral Weak Form Factors of the Nucleon

D. Beck, Spokesperson, P. Roos, Deputy Spokesperson
with collaborators from
Caltech, Carnegie Mellon, Hampton, Illinois, IPN Orsay, LPSC Grenoble, Jefferson Lab (Hall C), Kentucky, Louisiana Tech, Manitoba, Maryland, New Mexico State, Northern B.C., TRIUMF, William & Mary, Virginia Tech, Yerevan

1. Introduction

The G0 experiment will determine the neutral weak form factors of the nucleon by measuring parity-violating electron scattering from hydrogen and deuterium targets. By combining these form factors with those from ordinary electromagnetic scattering, the contributions of strange quarks to nucleon currents can be extracted.[1,2] It is important for our overall picture of the nucleon to understand the role of the gluon fields and associated sea quarks; measurements of the strange quark contributions to the ground state charge and magnetization distributions provide the only low energy observables of the sea that can be directly related to QCD.[3]

The experiment is run in two stages. In order to separate the charge and magnetic form factors, measurements at forward and backward angles are required. By detecting recoil protons, the forward angle electron scattering asymmetry can be measured over the complete momentum transfer range of the experiment, $0.1 \leq Q^2 \leq 1$ GeV^2. In the backward direction, individual measurements are required at each momentum transfer (each requiring different beam energies) and electrons are detected. Because there is a significant contribution to the asymmetries from the unknown axial-vector form factor, particularly at backward angles, quasi-elastic measurements using a deuterium target are also planned. In the case of deuterium, the predominantly isovector axial current changes relative to the isoscalar strange quark currents because of the additional scattering from the neutron. We will also be able to measure inelastic electron asymmetries in the backward measurements to study the neutral weak transition form factor of the Δ resonance.

2. Physics

The electroweak scattering of electrons by nucleons may be thought of in terms of the point-like interaction of photons and Z^0's with the point-like ('current') quarks in the nucleon. Although we cannot yet calculate the structure of the nucleon at this level, we can take advantage of the different relative coupling of the photon and Z^0 to separate the contributions of different flavors. For example, the ordinary charge form factor of the nucleon can be written as

$$G_E^{\gamma,p} = \frac{2}{3} G_E^{u,p} - \frac{1}{3}\left(G_E^{d,p} + G_E^{s,p}\right)$$

and the corresponding neutral weak analog is

$$G_E^{Z,p} = \left(1 - \frac{8}{3}\sin^2\theta_W\right) G_E^{u,p} - \left(1 - \frac{4}{3}\sin^2\theta_W\right)\left(G_E^{d,p} + G_E^{s,p}\right)$$

where the 'form factors' $G_E^{j,p}$ are the contributions of quark flavor j (actually the sum of contributions of quarks and anti-quarks) to the charge form factor of the proton. The key is that these same form factor contributions appear in both the electromagnetic and neutral weak form factors, but in different linear combinations. Assuming charge symmetry, the corresponding neutron form factor may also be written in terms of these contributions

$$G_E^{\gamma,n} = \frac{2}{3} G_E^{d,p} - \frac{1}{3}\left(G_E^{u,p} + G_E^{s,p}\right)$$

thereby allowing us to separate the strange quark contributions explicitly.

A number of nucleon models have attempted to include strange quark degrees of freedom, relying on hadronic expansions of baryon and meson resonances ('loop' calculations), vector dominance models of the photon-nucleon interaction ('pole' calculations), combinations of these (dispersion calculations), heavy baryon chiral perturbation calculations, $SU(3)_f$ Skyrme calculations, and lattice calculations. Most of the attention has been focused on the strange quark contribution to the magnetic moment, generally calculated to be negative and of order -0.2 n.m. A more comprehensive set of data over a range of momentum transfers from this and other experiments (SAMPLE, HAPPEX and other Hall A measurements, PVA4) will allow us to better understand the role of the strange quark mass and the interactions of sea quarks with the medium of the nucleon.

The axial current form factor measured in parity-violating electron scattering is similar to that measured in neutrino scattering (effectively the tree-level graph), with one important difference. Because the electron is charged, there is also an effective axial interaction of the photon which involves a weak interaction in the target – an effect known in general terms as the anapole interaction. It is therefore interesting because it is sensitive to the weak interaction between quarks in the nucleon and turns out to have sensitivity to quark orbital angular momentum.[4] This effect has been measured[5] and computed[6] in the SAMPLE measurement at MIT-Bates and is found to reduce the magnitude of the tree-level axial form factor by about 25%. In the G0 experiment, the momentum transfer dependence of this effective axial form factor, $G_A^e\left(Q^2\right)$, will be determined.

The asymmetries for backward angle inelastic electron scattering are expected to be dominated at the moderate momentum transfers of these measurements by the isovector axial N-Δ transition form factor, $G_{N\Delta}^A\left(Q^2\right)$. This form factor has previously been determined indirectly from pion electroproduction of the Δ resonance (e.g. JLab experiment 94-005), as well as from semi-leptonic charged current excitation. In the G0 experiment, the form factor is determined using the neutral current interaction. The results will help constrain the first order momentum transfer dependence of the form factor.

3. Apparatus

These measurements are being performed with dedicated apparatus in Hall C. It consists of specialized beam monitoring hardware, a cryogenic liquid hydrogen target and a toroidal superconducting spectrometer fitted with a symmetric array of detectors and associated data acquisition electronics. The spectrometer is designed to accept a 20 cm liquid target with a solid angle of about 0.9 sr. The detector system is replicated for each of the eight octants of the spectrometer.

In the forward measurement, the recoil protons are focused into one of 15 focal plane detectors (FPDs) per octant according to the Q^2 of the scattering; inelastic protons and pions are separated using time-of-flight (t.o.f.). The t.o.f. measurements are made possible by a special beam structure with pulses every 32 ns rather than the usual 2 ns. Because of the high rates in the experiment (~1 MHz per detector), counts are scaled according to t.o.f. by custom time encoding electronics.

In the backward scattering measurement, all detectors are used for the single Q^2 of the measurement. In this case, however, two additional detector elements are necessary. In order to separate elastic and inelastic electrons, a set of cryostat exit detectors (CEDs) are placed between the spectrometer and the FPDs. In addition, an aerogel Cherenkov detector is used to reject negative pions arising primarily from elementary production on

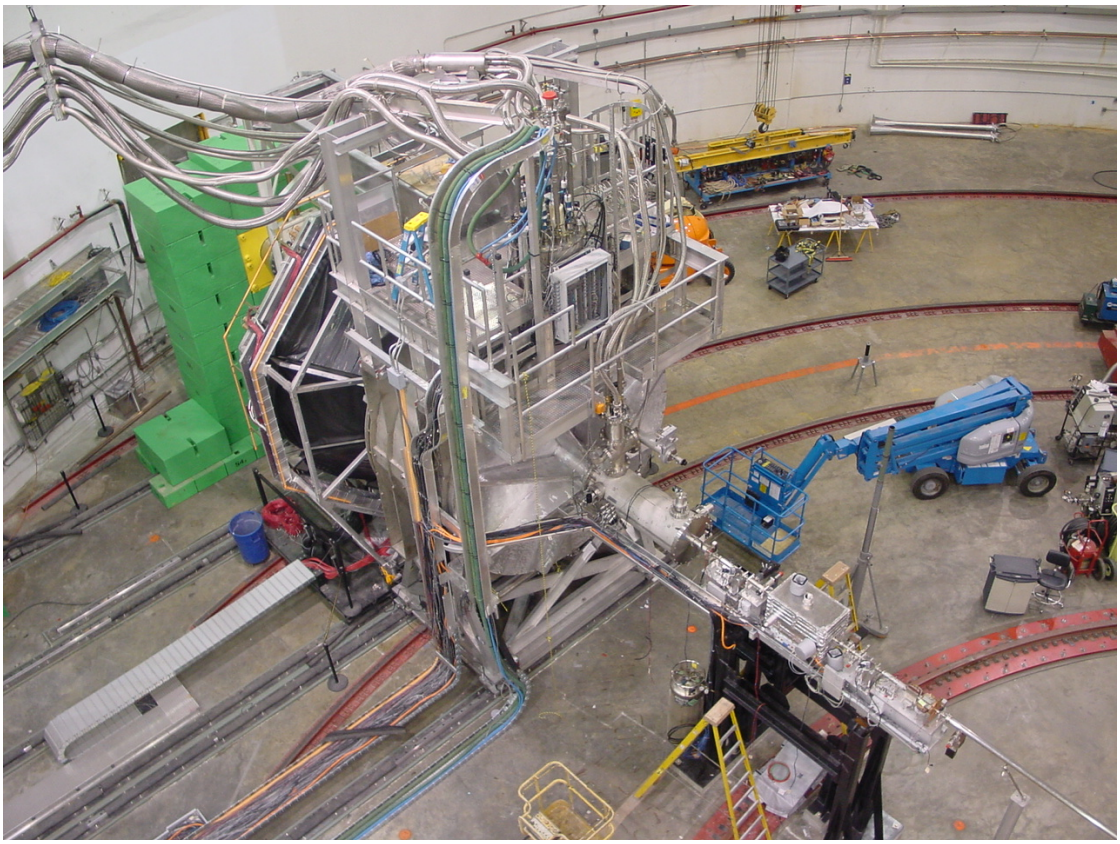

Figure 1 G0 experiment installed in Hall C. Installation was completed in October 2002.

neutrons (in the deuterium target and in the aluminum target windows). The forward angle electronics are supplemented with logic arrays to allow simultaneous measurement of elastic and inelastic electrons.

4. Status

In 2002/3 the G0 experiment was installed and completed its forward angle engineering runs. A photograph of the completed setup on the beamline in Hall C is shown in Figure 1.

During the first part of the engineering run for the experiment (winter 02-03), the basic function of all parts of the experimental apparatus was established. Operation of the magnet at full current (5000 A) was established early in the run. Target density fluctuations were measured by reducing the beam raster size and shown to be negligible as shown in Figure 2. The initial checkout of the detectors showed a low energy background originating from the beampipe downstream of the experiment. Lead shielding (at least 4 in.) around the beampipe reduced this background to manageable levels. Subsequently, good t.o.f. spectra, basically in accord with expectations, were obtained for all detectors as shown in Figure 3.

In the last part of the engineering run (winter 03-04), the parity-quality beam properties were established and several improvements were made to the setup. False asymmetries due to helicity-correlated changes in beam properties are controlled both by reducing the beam property changes and the sensitivity of the apparatus to them (typically by making the detector as symmetric as possible). In the end, the natural helicity-correlated changes in beam charge and position must be controlled using feedback. We have successfully demonstrated this control as shown in Figure 4. The main improvement in the setup was made in the target. From the first engineering run, we were able to determine that a substantial amount of the background under the elastic proton peak was due to inelastic protons from the aluminum target exit window. Between the runs, the central region of the window (~ 1 cm dia.) was thinned from 0.011 in. to 0.003 in. This contribution is

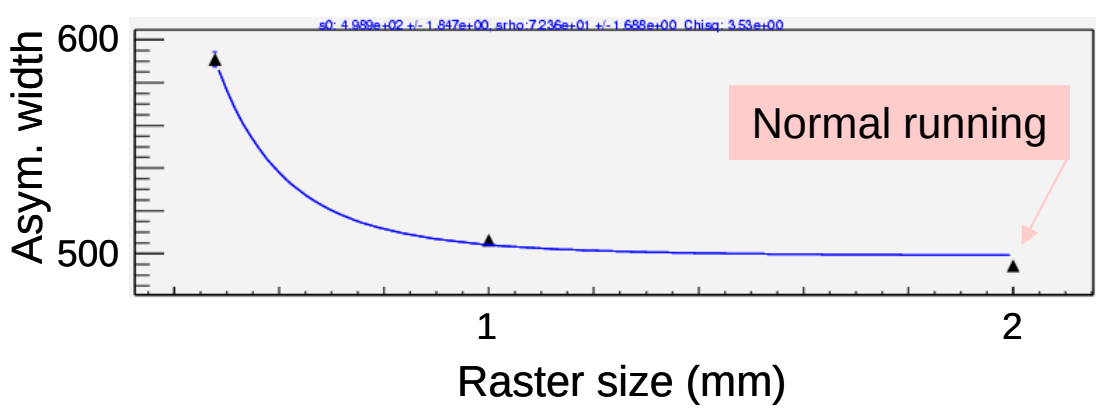

Figure 2 The effect of density fluctuations in the target are determined by measuring the change in width of the detector yield (asymmetry) as a function of beam power density at the target (changed by varying the beam raster size).

now comparable to that from the corresponding entrance windows (each about 3%). Separate runs on gaseous H_2 and Al targets, together with the asymmetries measured for the inelastic protons near the elastic peak are used to remove the background contribution from the elastic asymmetry.

The engineering runs have been completed, with the experimental apparatus performing as designed. Production running for the forward angle measurement is expected to take place in spring 2004, with the backward angle turnaround and running to follow.

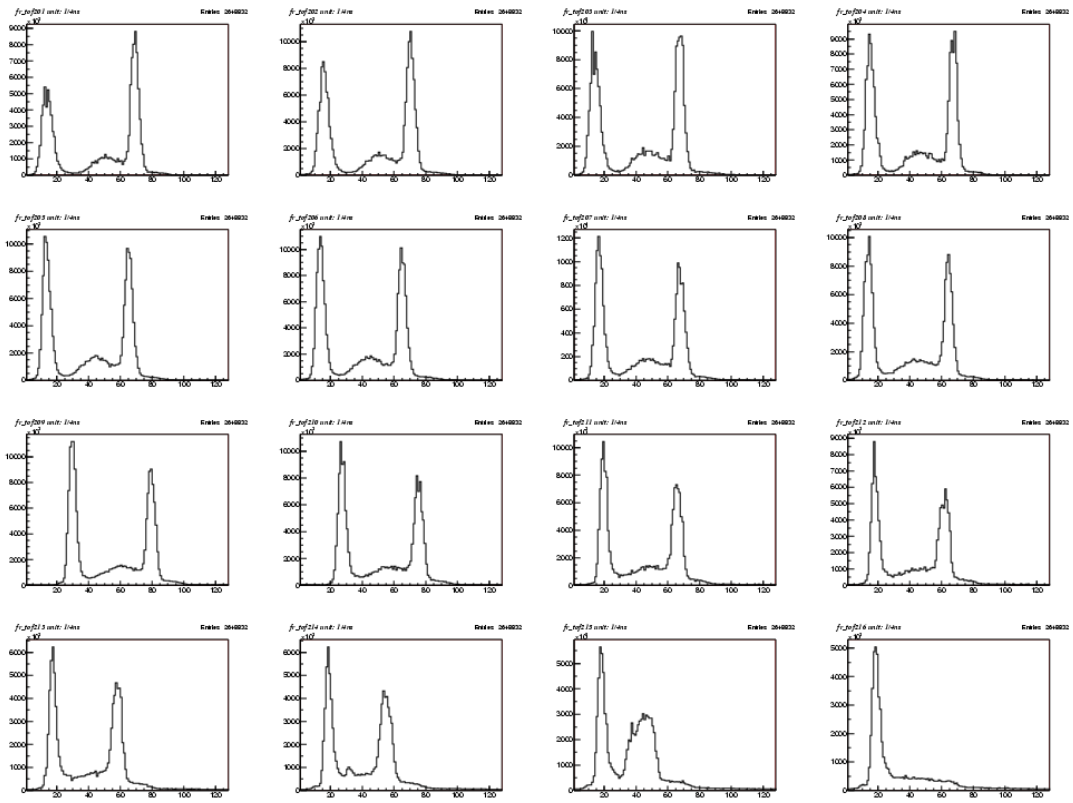

Figure 3 T.o.f. spectra (1/4 ns/channel) for the 16 detectors (1-4 in the first row, etc.) of a single octant. The peak to the right is due to elastic protons, that to the left to pions. Inelastic protons appear in the intermediate region. Elastic protons appear in a limited region on the focal surface with the lowest Q^2 events in detector 1 – detector 16 is purposely placed just beyond the edge of this acceptance as a monitor. Protons corresponding to the highest momentum transfers wrap around in detector 15 (hence the width of the peak) and appear twice in detector 14.

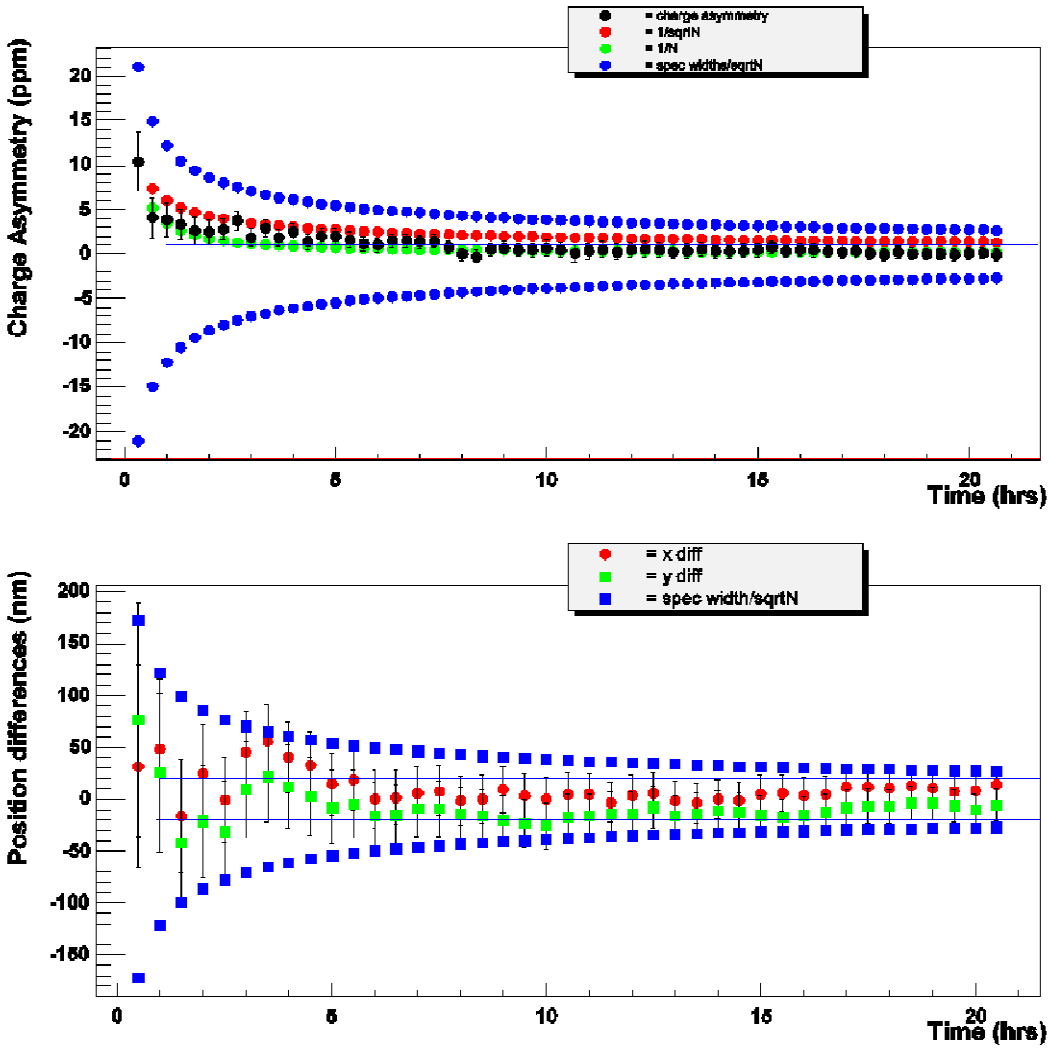

Figure 4 Convergence of feedback systems for helicity-correlated beam current (charge) asymmetry (top) and position differences (bottom). After a few hours, the charge asymmetry is controlled at the 1 ppm level and the position differences to 20 nm – the specs for the experiment. The points with the error bars are the cumulative asymmetries/differences in each case; the dots represent various convergence criteria

---

[1] R. D. McKeown, Phys. Lett. **B219** (1989) 140.
[2] D. H. Beck, Phys. Rev. D **39** (1990) 3248.
[3] For recent reviews, see D. H. Beck and R. D. McKeown, Ann. Rev. Nucl. Part. Sci. **51** (2001) 189; D. H. Beck and B. Holstein, Int. J. Mod. Phys. **E10** (2001) 1; and K. Kumar and P. Souder, Prog. Nucl. Part. Phys. **45** (2000) S333.
[4] C. Bouchiat and C. Piketty, Z. Phys. **C49** (1991) 91.
[5] SAMPLE collaboration, T. M. Ito et al., subm. Phys. Rev. Lett. (nucl-ex/0310001).
[6] S. –L. Zhu, et al. Phys. Rev. D **62** (2000) 033008.