Jefferson Lab PAC15
Proposal Cover Sheet

This document must be received by close of business Thursday, Dec 17, 1998 at:

Jefferson Lab
User Liaison,
Mail Stop 12B
12000 Jefferson Ave.
Newport News, VA
23606

Experimental Hall: C

Days Requested for Approval: 46

❒ Proposal Title:

G0 Experiment

Proposal Physics Goals

Indicate any experiments that have physics goals similar to those in your propos

Approved, Conditionally Approved, and/or Deferred Experiment(s) or proposals:

91-010, 91-004, 93-022

Contact Person

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Jefferson Lab Use On

Receipt Date: 12/17/98 PR 99-016

By: [redacted]

BEAM REQUIREMENTS LIST

JLab Proposal No.: _____ Date: 16 December 1998

Hall: C Anticipated Run Date: 2001 PAC Approved Days: (46 in 1993)

Spokesperson: Doug Beck
Phone: (217) 244-7994
E-mail: dhbeck@uiuc.edu

Hall Liaison: Allison Lung

List all combinations of anticipated targets and beam conditions required to execute the experiment. (This list will form the primary basis for the Radiation Safety Assesment Document (RSAD) calculations that must be performed for each experiment.)

Condition No.	Beam Energy (MeV)	Mean Beam Current (μA)	Polarization and Other Special Requirements (e.g., time structure)	Target Material (use multiple rows for complex targets — e.g., w/windows)	Material Thickness (mg/cm²)	Est. Beam-On Time for Cond. No. (hours)
1.	3000	40	max. pol'n; 31.25 MHz	LH_2	1400	1050
2.	3000	40	" "	He	96	50

The beam energies, E_{Beam}, available are: $E_{Beam} = N \times E_{Linac}$ where N = 1, 2, 3, 4, or 5. E_{Linac} = 800 MeV, i.e., available E_{Beam} are 800, 1600, 2400, 3200, and 4000 MeV. Other energies should be arranged with the Hall Leader before listing.

HAZARD IDENTIFICATION CHECKLIST

JLab Proposal No.: _____ Date: 16 December 1998
(For CEBAF User Liaison Office use only.)

Check all items for which there is an anticipated need.

Cryogenics

- ____ beamline magnets
- x analysis magnets
- x target
  - type: LH_2
  - flow rate: 5 l/s
  - capacity: 6.6 l LH_2

Electrical Equipment

- x cryo/electrical devices
- ____ capacitor banks
- x high voltage
- ____ exposed equipment

Radioactive/Hazardous Materials

List any radioactive or hazadorous/ toxic materials planned for use:

Pressure Vessels

- ____ inside diameter
- ____ operating pressure
- ____ window material
- ____ window thickness

Flammable Gas or Liquids

- type: LH_2
- flow rate: 5 l/s
- capacity: 6.6 l LH_2

Drift Chambers

- type: ____
- flow rate: ____
- capacity: ____

Other Target Materials

- ____ Beryllium (Be)
- ____ Lithium (Li)
- ____ Mercury (Hg)
- ____ Lead (Pb)
- ____ Tungsten (W)
- ____ Uranium (U)
- ____ Other (list below)

Vacuum Vessels

- 4 m inside diameter
- vac operating pressure
- Ti window material
- 1/64 in window thickness

Radioactive Sources

- ____ permanent installation
- x temporary use
- type: ^{106}Ru ^{60}Co
- strength: 1 mCi 100 uCi

Large Mech. Structure/System

- ____ lifting devices
- ____ motion controllers
- x scaffolding or
- x elevated platforms

Lasers

- type: UV N_2
- wattage: ~~7 mW~~ 5 mW
- class: I IIb

Installation:

- x permanent
- ____ temporary

Use:

- x calibration
- ____ alignment

Hazardous Materials

- ____ cyanide plating materials
- ____ scintillation oil (from)
- ____ PCBs
- ____ methane
- ____ TMAE
- ____ TEA
- ____ photographic developers
- ____ other (list below)

General:

Experiment Class:

- ____ Base Equipment
- ____ Temp. Mod. to Base Equip.
- ____ Permanent Mod. to Base Equipment
- x Major New Apparatus

Other: ____

LAB RESOURCES LIST

JLab Proposal No.: _____ Date 16 December 1998

(For JLab ULO use only.)

List below significant resources — both equipment and human — that you are requesting from Jefferson Lab in support of mounting and executing the proposed experiment. Do not include items that will be routinely supplied to all running experiments such as the base equipment for the hall and technical support for routine operation, installation, and maintenance.

* For details see G0 Management Plan

Major Installations *(either your equip. or new equip. requested from JLab)*

G0 Spectrometer System

New Support Structures: detector

Data Acquisition/Reduction

Computing Resources: target control software
slow control software

New Software:

Major Equipment

Magnets:

Power Supplies: Dynapower supply for G0 magnet

Targets:

Detectors:

Electronics: infrastructure as in Management Plan

Computer Hardware:

Other:

Other:

PAC Jeopardy Proposal
The G^0 Experiment (Originally E91-017)

The G^0 Collaboration
American University, California Institute of Technology, Carnegie-Mellon University, College of William and Mary, Hampton University, L'Institut de Physique Nucléaire d'Orsay, L'Institut des Sciences Nucléaires de Grenoble, Thomas Jefferson National Laboratory, Louisiana Tech. Univeristy, New Mexico State University, North Carolina A&T State University, TRIUMF, University of Illinois at Urbana-Champaign, University of Connecticut, University of Manitoba, University of Maryland, University of Massachusetts, University of Northern British Columbia, and Virginia Tech.

December 1998

Contents

1 Overview **1**

1.1 Introduction 1

1.2 Experiment 3

2 Physics **7**

2.1 Introduction 7

2.2 Flavor-dependent nucleon currents 8

2.3 Parity-violating elastic electron scattering 10

2.4 Expected Results 11

3 Relation to Other Experiments **15**

3.1 HAPPEX 15

3.2 Relation to Other PV Measurements 15

3.3 Relation to ϕ Photoproduction 16

4 G^0 Management Organization **17**

5 Subsystem Descriptions and Progress **25**

5.1 Introduction 25

5.2 Integrated Superconducting Magnet Subsystem 25

5.2.1 Superconducting Toroid (BWXT) 25

5.2.2 Collimation and Shielding Modules (UIUC) 25

5.2.3 Carriage (UIUC) 26

5.2.4 Vacuum Windows (UIUC) 26

5.2.5 External Shielding Collar (UIUC) 26

5.2.6 Optical Verification (UIUC) 26

5.2.7 Magnetic Verification (TRIUMF/ UIUC) 27

5.2.8 NPL Infrastructure (UIUC) 27
5.3 Target Subsystem 27
5.4 Detector Subsystem 29
5.4.1 North American Detectors 29
5.4.2 French Detectors 32
5.4.3 Cryostat Exit Detectors 33
5.5 Electronics Subsystem 34
5.6 Infrastructure 36
5.6.1 G^0 Installation & Shielding 36
5.6.2 Hall C Electrical 36
5.6.3 Beamline Elements 37
5.6.4 Cryogenic Services 37
5.6.5 Engineering and Design 37
5.6.6 Support Structures 38
5.7 Computation 38
5.7.1 Slow Controls 38
5.7.2 Data Acquisition 39
5.7.3 Analysis 39
5.7.4 Simulation 39

6 Beam Time Request **41**

1 Overview

1.1 Introduction

This proposal has been prepared for the review of the G^0 experiment by the Jefferson Lab Program Advisory Committee. The G^0 experiment was previously approved as experiment 91-017 with A priority in December 1993. This proposal has been prepared in accordance with the "jeopardy" rules of Jefferson Lab.

In this experiment, the parity-violating asymmetry in elastic electron scattering from the proton will be measured at both forward and backward angles and over a range of momentum transfers from about 0.1 – 1.0 GeV^2. A single measurement of the backward angle parity-violating quasi-elastic scattering from the deuteron will be measured*. The primary purpose of the experiment is to separate the s quark contributions to the overall charge and magnetization densities of the nucleon using these measurements. No other proposed experiment will perform directly this separation. A special purpose, superconducting toroidal spectrometer with large azimuthally symmetric angular acceptance is being constructed for these measurements.

There has been a great deal of progress in development of the experiment as will be summarized in this report:

- funding of $2.25M from NSF, October 1995 for the magnet and target subsystems;
- magnet RFP, May 1996;
- magnet contract signed, May 1997;
- Cost and Schedule Review, February 1998;
- G^0 Management Plan, November 1998;
- agreement on funding $0.952M from DOE, $2.194M from Jefferson Lab, $0.493M additional funding from NSF, $0.229M from ongoing grants, December 1998
- target Preliminary Design Review, December 1998; and
- expansion of collaboration from about 40 to about 80 members, including addition of large groups from Canada and France (Table 1.1)

We request at this time that the PAC approve the original 46 days (1100 hours) for commissioning the experiment (see Section 6 at the end of this proposal). The commissioning plan is, at this time, basically unchanged from what was envisioned at the time of the original approval. The recent decision (October 1998) to locate the experiment downstream of the standard Hall C pivot may preclude breaking the commissioning run into three pieces; nevertheless the same jobs must be completed. At a future date we will request approval for the first physics running.

A summary of the experiment is provided in the following subsection. This is followed by a more detailed discussion of the physics, presentation of the management and schedule

*The deuterium measurement is used to determine the axial radiative correction

California Institute of Technology				
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Carnegie-Mellon University				
R. Clark	G. Franklin	J. Lachniet	R. McCrady	C. Meyer
B. Quinn†	R. A. Schumacher			
College of William and Mary				
D. S. Armstrong	T. Averett	J. M. Finn	K. Griffioen†	
Hampton University				
K. McFarlane†				
IPN-Orsay				
J. Arvieux†	L. Bimbot	R. Frascaria	M. Morlet	E. Rollinde de Beaumont
L. Rosier	J. van de Wiele			
ISN-Grenoble				
C. Furget	S. Kox†	L. Lu	E. Liatard	F. Merchez
J. Pouxe	G. Quemener	J. Real	P. Stassi	R. Tieulent
E. Voutier				
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K. Johnston†	J. Price	N. Simicevic	S. Wells	
New Mexico State University				
G. Kyle	V. Papavassiliou†	S. Pate†		
North Carolina A&T State University				
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American University				
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TJNAF				
P. Brindza	R. D. Carlini†	A. F. Lung†	D. J. Mack	W. F. Vulcan
S. A. Wood	C. Yan			
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University of Illinois				
D. H. Beck†	C. Bochna	M. Brussel	J. Grames	R. Holt
R. Laszewski†	A. M. Nathan	B. Terburg	S. Williamson†	
University of Manitoba				
J. Birchall	W. R. Falk	L. Lee	S. A. Page	W. D. Ramsay
W. T. H. van Oers†	R. J. Woo			
University of Maryland				
E. J. Beise†	D. S. Brown	H. Breuer	N. Chant	A. Cowley
P. Roos				
University of Massachusetts				
B. R. Holstein†				
University of Northern British Columbia				
E. Korkmaz†	G. V. O'Rielly			
Virginia Tech				
M. L. Pitt†				

Table 1.1: Participants in the G^0 collaboration († indicates contact person).

for the experiment, and more detailed descriptions and updates on the status of various subsystems. We conclude with the beam time request.

1.2 Experiment

In this experiment, parity-violating electron scattering asymmetries will be measured in the range $0.1 \lesssim Q^2 \lesssim 1.0$ GeV^2 at both forward and backward angles. These pairs of measurements will allow us to separate the form factors G_E^Z and G_M^Z (neutral weak current analogs of the ordinary G_E and G_M). The asymmetries range from about -3 to -35×10^{-6}; we are planning to measure the asymmetries with statistical uncertainties of $\Delta A/A \cong 5\%$ and systematic uncertainties related to helicity-correlated effects of $\Delta A \leq 2.5 \times 10^{-7}$. We note that the small systematic uncertainties achieved in the recent HAPPEX experiment at Jefferson Lab suggest that we can meet this goal. Initially, we will measure concurrently the forward angle asymmetries binned in seven values of momentum transfer in the range $0.1 \lesssim Q^2 \lesssim 1.0$ GeV^2. Assuming a beam polarization of 49%, the time required to reach this precision for the initial measurement will be about 30 days. There is good reason to expect that by the time of the experiment, higher beam polarizations will be available for parity-violation experiments, which would improve the statistical precision by a factor of about 1.5 in this running period. (Using the G_M^s ($Q^2 = 0.1$ GeV^2) result from the SAMPLE experiment now completed at Bates, it would be possible to separate the charge and magnetic form factors in the lowest Q^2 bin after this first measurement.) *Each* subsequent backward angle asymmetry, measured with comparable precision to the forward asymmetries, would require 30 days of running time.

To achieve the desired precision in a reasonable amount of time, this experiment must be run at high luminosity with a large-acceptance detector. The layout of the experiment is shown in Figure 1.1. First, for the forward angle asymmetries, we propose to measure elastically scattered protons ($0.35 \leq p_p' \leq 1.1$ GeV with $76° \geq \theta_p' \geq 52°$, respectively; the electron beam energy will be 3.0 GeV and the beam current 40 μA. The solid angle acceptance for the forward angle measurement is about 0.9 sr. Second, for the backward angle asymmetries, the spectrometer will be turned around to detect electrons at the complementary angle centered at about 110° with a solid angle acceptance of from 0.9 sr at $Q^2 = 0.2$ GeV^2 to about 0.5 sr at $Q^2 = 1$ GeV^2; the beam energies will range from 0.34 to 0.93 GeV. There is also acceptance for inelastically scattered electrons in the backward angle measurement; this is the subject of approved proposal 97-104.

The polarized electron source requirements for this experiment are the responsibility of the injector group at Jefferson Lab. It must operate in a "pulsed" mode to allow for time-of-flight measurements (see below) wherein only one of every sixteen of the normal beam buckets (at 499 MHz) are filled. This mode will be effected with a special laser running at 499/16 MHz. The average current for which the experiment is designed, 40 μA, is therefore generated from pulses with peak currents 16 times as large as "normal" (but about 3 times the peak current required for a 200 μA beam). These high peak currents will require careful study and possible modification of the gun optics to account for the increased effects of space charge. We are, of course, interested in utilizing higher polarization cathodes for

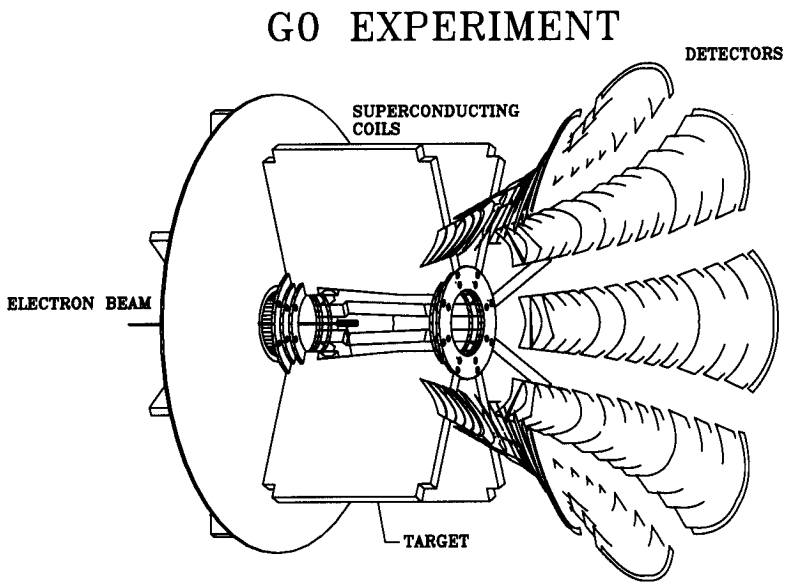


Figure 1.1: Schematic view of the G^0 experiment showing the spectrometer in the forward angle configuration (protons detected). Two of the eight coils and one sector of detectors have been removed for clarity.

the experiment. Strained crystals pose special problems for parity-violation experiments because of larger helicity-correlated current and position differences (resulting at least in part from the effective analyzing power of the strained surface for residual linearly polarized components of the laser light). Mark Pitt of Virginia Tech will be the injector group liaison for the G^0 Collaboration.

The spectrometer being constructed for this experiment provides the unique capability of measuring both the forward and backward angle asymmetries. It consists of a toroidal array of eight superconducting coils with a field integral of approximately 1.6 T·m. The spectrometer is designed to focus particles of the same momentum and scattering angle from the length of the extended target to a single point (zero magnification in the dispersion direction) in each of the eight identical sectors of the spectrometer. The bend angle of about 35° at the highest momentum is sufficient to allow complete shielding of the detectors. Careful collimation reduces the contamination of inelastic protons (electrons) in the acceptance of elastically scattered protons (electrons). The spectrometer has a number of advantages for this parity-violation experiment. We are able to access relatively high momentum transfers using a magnet that has a maximum momentum of less than 1 GeV. It has very large solid angle and momentum acceptance. The solid angle acceptance is axially symmetric and thus susceptibility to systematic uncertainties is reduced. The shape of the field is determined by the current conductors, there is no polarized iron in the system, and the magnetic field at the target is zero.

The target for the experiment is a thin-walled, 5 cm diameter, 20 cm long vessel of liquid hydrogen; cooling required for the experiment is about 250 W. The design is a combination of those used for the successful SAMPLE (500 W) and Jefferson Lab targets. It consists

of the hydrogen cell, a helium cell to maintain consistent curvatures at both ends of the primary cell, together with a cooling loop containing a heat exchanger, pump and heaters. This loop is situated inside the bore of the spectrometer magnet; tests have been performed to ensure the operation of the motor in the magnetic field.

In the G^0 experiment, we will count individual particles rather than to integrate the signal in the detectors. Particle counting affords the possibility of using standard time-of-flight and coincidence techniques to supplement the resolution of the spectrometer and suppress backgrounds. For both the forward and backward measurements, there will be 16 scintillators in each sector of the focal surface shaped to accept a narrow range of particle momenta. In the case of the forward measurement each of the scintillators will be paired with a second identically shaped partner to reduce background from neutral particles (this set of detectors together are the Focal Plane Detectors – FPDs). Time-of-flight (using a beam with only one of sixteen of the normal 499 MHz beam buckets filled) will be used to separate prompt particles, including pions, photons and electrons, from protons in the forward measurement. In the case of the backward measurement, a set of smaller scintillators (Cryostat Exit Detectors CEDs) located near the magnet exit window will be used in conjunction with the 16 focal surface detectors to effectively determine the momentum and scattering angle of the electrons. These detectors are therefore used to separate the elastic and inelastic electrons.

The electronics used for the experiment will involve a mixture of custom and commercial components. Two different types of readout electronics systems will be utilized. In each case, time-of-flight will be decoded for each event and effectively histogrammed in scalers. Four sectors ("North American") will be instrumented with shift-register-based time encoding; four sectors ("French") will be instrumented with either integrated shift-register-based encoders or flash-TDC/Digital-Signal-Processor encoders. Some time-of-flight capability will be retained for the backward angle measurements; in addition the combinations of CEDs and FPDs necessary to record both elastic and inelastic events will be accommodated.

Various types of backgrounds have been investigated for both forward- and backward-angle measurements. Prior to the original proposal, the inelastic proton background in the forward measurement was measured at SLAC under essentially the same kinematic conditions. It was found to be approximately consistent with the predictions of Lightbody and O'Connell. Backgrounds from pions, neutrons and positrons have been simulated and found to be small in the time region of interest. We note that the asymmetry of the combined backgrounds (inelastic protons and electrons, neutrons, pions, photons, etc.) is measured simultaneously in time bins which do not contain the elastic protons or electrons. In the case of the backward angle measurements where the electrons are detected, π^-s are kinematically forbidden from the elastic acceptance for momentum transfers extending above 1 GeV^2; by means of the CEDs, elastic and inelastic electrons are adequately separated. A more complete version of the GEANT MC used for many of these studies is currently being constructed to include more precisely the actual geometry of the spectrometer.

Precise monitoring and control of the beam will be required for this experiment. For each measurement interval the beam characteristics – position, angle, energy and charge

must be measured. Based on the present design of the experiment, position measurements with precision on the order of 25 μm will be required for each measurement interval (the most stringent requirements are for the position measurements used to determine the beam energy centroid). A system to allow the entire experiment, including the key beam monitoring devices, to be "rolled" in and out of the beamline is being presently being developed at Jefferson Lab. It will allow the experiment to be reinstalled with minimum cryogenic, mechanical and electrical work.

2 Physics

2.1 Introduction

As indicated above, the primary purpose of this experiment is to determine the s quark contributions to the overall charge and magnetization densities of the nucleon. As will be demonstrated below the goal is to determine these s quark contributions at a level of a few percent of these form factors over the range of momentum transfer from about 0.1 to 1.0 GeV^2.

There have been several indications that strange quarks play some role in nucleon properties:

1. s quarks carry a few percent of the nucleon momentum as determined from charm production in deep inelastic neutrino scattering from nucleons [Ba95]. They carry about half the average momentum carried by u and d sea quarks.
2. Many analyses of spin-dependent deep inelastic lepton scattering from the nucleon indicate a negative s quark polarization at about the 10% level [Ad97, Ab98].
3. The scalar strange quark matrix element in the nucleon may be as large as 1/2 that of the u and d quarks as determined from the discrepancy between the calculated πN Σ term and that determined from experiment [Be96].
4. The strong enhancement of ϕ production relative to that of ω compared to a simple OZI rule calculation in some $\bar{p}p$ annihilation channels can be interpreted in terms of $\bar{s}s$ knockout [Ma98].

Among other things, the interest in s quark matrix elements in the nucleon, especially at low momentum transfers, derives from the constraint that they must be part of the sea – about which we have little direct information. As will be shown below, the neutral weak interaction vector matrix elements, together with measured electromagnetic (vector) matrix elements provide an essentially model independent determination of their s quark contributions.

The expectations for these contributions from the point of view of theory vary widely [Mu94, Be96a]. In general, these measurements will tell us about the interactions of $\bar{s}s$ pairs and thereby provide some constraints on $\bar{u}u$ and $\bar{d}d$ pairs as well. The measurements of the momentum fraction clearly indicate the presence of $\bar{s}s$ pairs in the nucleon; the vector currents measured here will essentially indicate whether these pairs survive long enough to interact and become spatially separated to a degree significant compared with the range corresponding to the momentum transfers probed. A small or zero contribution to these currents has been described as a signal that the $\bar{s}s$ pairs are effectively "inert" [Mu98].

We cite here as examples two representative contexts for understanding the physics of the results: first, the current thinking regarding the hadronic expansion of QCD; and second, the relation to lattice QCD calculations.

Two recent papers contrast the current thinking in relation to such a picture. First, in a calculation by Geiger and Isgur [Ge97], a study is made of the contributions of an extended set of excited state kaons and hyperons to the strange quark currents in the nucleon. They find strong cancellations as the series is extended – in the pure SU(6) limit and a complete set the result is identically zero. The authors conclude that "If correct our conclusions rule out the utility of a search for a simple but predictive low energy hadronic truncation of QCD". On the other hand, the recent data from experiment E866 at FNAL measuring the $\bar{d} - \bar{u}$ asymmetry in the nucleon (Gottfried Sum Rule violation) leads to the following conclusion "The good agreement between the E866 $\bar{d} - \bar{u}$ data and the virtual pion model indicates that virtual meson-baryon components play an important role in determining the non- singlet structure functions of the nucleon" [Pe98]. It is clear that these issues will remain at the center of discussion about nucleon structure for some time to come. The detailed measurements of the $\bar{s}s$ sea proposed herein, basically the complete set for this type of measurement, will have significant impact on these questions.

One of the hopes for unraveling nucleon structure is lattice QCD. In this case, in order to make progress with respect to understanding details of the quark sea, one of the most vexing problems in lattice QCD – the inclusion of dynamical fermions – must be addressed. There has been some progress recently in "first principles" inclusion of dynamical fermions accruing from developments related to "improved" and "perfect" actions [Bi98]. A lattice calculation using these new techniques is now on the verge of being a possibility [Ne98]. At this point there exists a lattice calculation [Do98] with some approximations in the treatment of the $\bar{q}q$ pairs. The results are shown in Figure 2.1. It is interesting to note that although the calculation does not reproduce the SAMPLE measurement, it is consistent with the HAPPEX result (in this case G_E^s and G_M^s are of opposite sign and the appropriate magnitude to effectively cancel in the measured combination). A complete set of $\bar{s}s$ contributions to the nucleon current as derived from these measurements can provide an important meeting between experiment and calculations on the lattice. Given the sheer size of these calculations, it will in general be important to have experimental benchmarks of this sort to help form a picture of nucleon structure from the calculational output.

2.2 Flavor-dependent nucleon currents

The electroweak probe provides a precise means of studying the currents of point-like quarks inside the nucleon. Because they are assumed to be Dirac particles in QCD, their (vector) currents are written simply as

$$\mathcal{J}_\mu^{ew} = \mathcal{Q}\bar{q}\gamma_\mu q$$

where $\mathcal{Q}$ is the charge appropriate to γ (ordinary electromagnetic charge) or Z^0 (neutral weak "charge", see below) coupling. The total electroweak current of the nucleon can then be written as a sum of the contributions from each of the quark flavors [Ca78, Ka88, Mc89, Be89, Na91]. For example, the electromagnetic form factors can be divided up in this way

$$G_{E,M}^{p,\gamma} = \sum_j \mathcal{Q}_j G_E^{j,p}$$

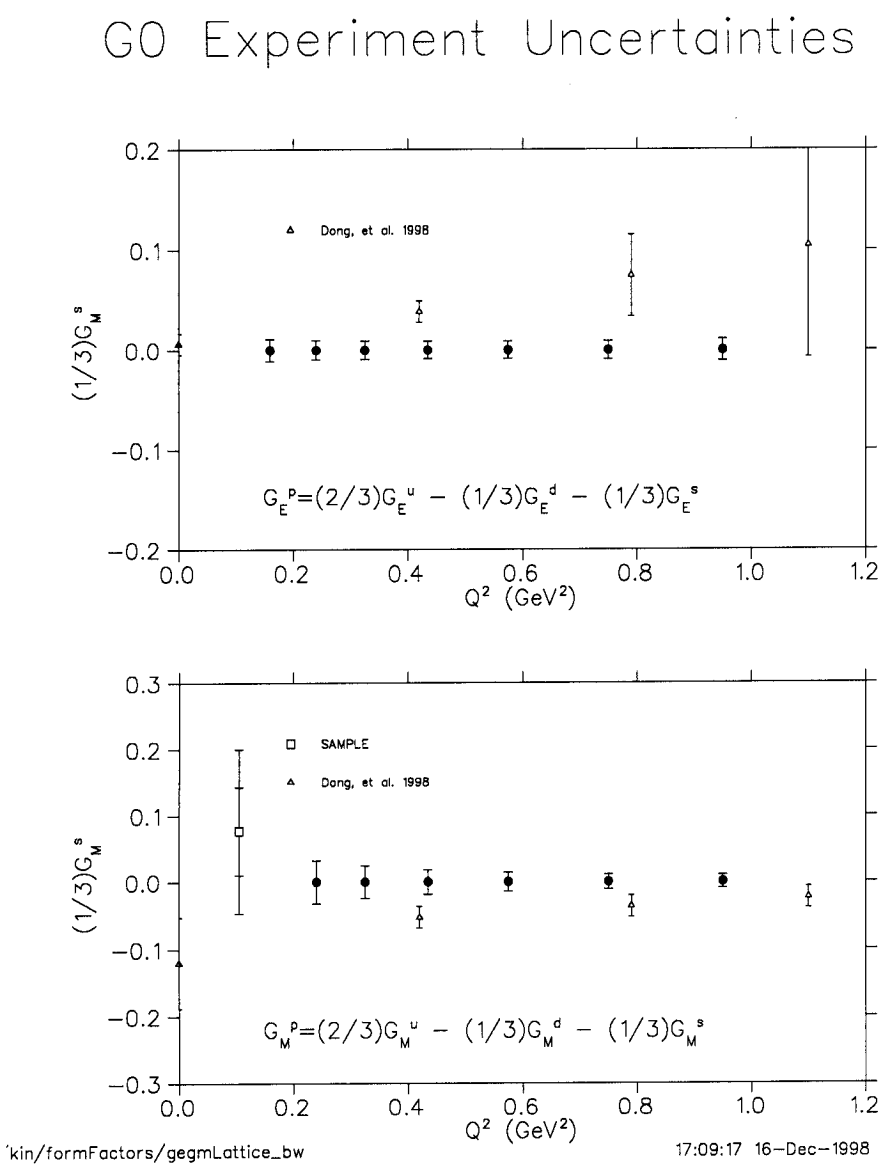


Figure 2.1: Lattice calculation of G_E^s and G_M^s together with the expected results from the G^0 experiment (solid symbols). Overall uncertainties are plotted for the experiment.

where j runs over all quark flavors and $\mathcal{Q}_j$ is the electric charge. (We note that this is an exact statement.) In what follows the contributions of the quarks and antiquarks of a given flavor are combined. For example, $G_E^{u,p}$ will represent the net contribution of u and $\bar{u}$ quarks to the charge form factor. The expression for the electromagnetic form factors is then

$$G_{E,M}^{p,\gamma} = \frac{2}{3}G_{E,M}^{u,p} - \frac{1}{3}G_{E,M}^{d,p} + \ldots$$

The utility of measuring the corresponding weak neutral current of the nucleon (in this case via parity-violating electron scattering, see Section 2.3) is that it can also be written

in terms of the $G_{E,M}^{j,p}$

$$G_{E,M}^{p,Z} = \sum_j \left(\frac{1}{2}T_j^3 - Q_j \sin^2\theta_W\right) G_{E,M}^{j,p}$$

where $\left(1/2\,T_j^3 - Q_j \sin^2\theta_W\right)$ is the weak "charge". This in turn suggests that the contributions of the quark flavors may be separated experimentally.

In order to determine $G_E^{s,p}$ or $G_M^{s,p}$, the s quark vector current matrix elements of the proton ("s quark form factors"), *three* measurements are required (in addition to the assumption that c and heavier quarks do not contribute significantly). In addition to the form factors $G_E^{p,\gamma}$ and $G_E^{p,Z}$ it is possible to make use of $G_E^{n,\gamma}$ *if* a model of the relation between proton and neutron structure is assumed. The simplest relationship is that interchanging u and d quarks will transform a neutron into a proton and vice versa (isospin symmetry), i.e., in this language

$$\begin{aligned} G_{E,M}^{u,p} &= G_{E,M}^{d,n} \\ G_{E,M}^{d,p} &= G_{E,M}^{u,n} \\ G_{E,M}^{s,p} &= G_{E,M}^{s,n} \end{aligned}$$

The s quark form factors are then

$$G_{E,M}^{s} = \left(1 - 4\sin^2\theta_W\right) G_{E,M}^{p,\gamma} - G_{E,M}^{n} - 4G_{E,M}^{p,Z}$$

with similar expressions for the u and d quark form factors. We note that this experiment will allow the three pairs of form factors $G_{E,M}^{\gamma,p}$, $G_{E,M}^{\gamma,n}$ and $G_{E,M}^{Z,p}$ to be written as the set $G_{E,M}^{u}$, $G_{E,M}^{d}$ and $G_{E,M}^{s}$. The u and d form factors, combinations of valence and sea contributions, also contain interesting information. The non- zero neutron charge radius, for example, suggests rather different u and d form factors. [Be92]

It is possible that s quarks could show up in either G_E or in G_M if they are significant. In order to contribute to the charge form factor there must be a "polarization" of the s and $\bar{s}$ distributions, i.e. they must have different spatial distributions. The presence of s and $\bar{s}$ with different angular momenta – opposite m_l, for example – would result in a contribution to G_M. A variety of combinations is therefore plausible in which s quarks would contribute more to one form factor than the other. It should be noted that at present no microscopic model is capable of realistically linking the contributions to the charge and magnetic form factors.

2.3 Parity-violating elastic electron scattering

Electron scattering by current distributions is described by the coherent sum of γ and Z^0 amplitudes

$$\mathcal{M} = \mathcal{M}^\gamma + \mathcal{M}^Z$$

although we tend to ignore $\mathcal{M}^Z$ since it is very small, roughly 10^{-5} as large as $\mathcal{M}^\gamma$. However, $\mathcal{M}^Z$, unlike $\mathcal{M}^\gamma$, has both vector and axial-vector pieces. Therefore, the cross term in the cross section violates parity.

The cross term can be determined experimentally by comparing two parity-sensitive cross sections whose parity-conserving parts are identical. In this case the two cross sections are those of longitudinally polarized electrons with positive and negative helicities. Because the parity-violating terms in the cross sections are proportional to the electron helicity, the asymmetry is directly related to the cross term, i.e.

$$A = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-} \propto \mathcal{M}^\gamma \mathcal{M}^Z / |\mathcal{M}^\gamma|^2.$$

In terms of the form factors defined earlier, at tree level, the asymmetry for elastic $\vec{e}p$ scattering is [Ca78, Mc89, Be89, Na91]

$$A = -\frac{G_F Q^2}{\pi\alpha\sqrt{2}} \{A_E + A_M + A_A\} / A_D$$

where

$$\begin{aligned} A_E &= \varepsilon\, G_E^\gamma G_E^Z, \\ A_M &= \tau\, G_M^\gamma G_M^Z, \\ A_A &= -\frac{1}{2}(1 - 4\sin^2\theta_W)\sqrt{\tau(1+\tau)(1-\varepsilon^2)}\, G_M^\gamma G_A^Z, \\ A_D &= \varepsilon\,(G_E^\gamma)^2 + \tau\,(G_M^\gamma)^2, \end{aligned}$$

and

$$\varepsilon = \left[1 + 2(1+\tau)\tan^2\theta/2\right]^{-1}$$

Note that ε can be varied between zero and unity for a fixed Q^2 by varying the beam energy and electron scattering angle. The "axial-vector" term proportional to G_A^Z arises from the axial-vector current in the proton which may couple directly to the Z^0. Note that it is suppressed relative to the vector "electric" and "magnetic" terms because of the factor $(1 - 4\sin^2\theta_W) \approx 0.08$.

2.4 Expected Results

The expected results for the experiment are shown in Figure 2.2. The uncertainties in shown in these plots include both statistical and systematic uncertainties as shown in Figures 2.3 and 2.4. Also shown in Figure 2.2 is (1/10 times) the dipole form factor in each case to indicate the precision of the measurement of the strange quark contribution relative to the overall form factor. We note that the precision of the measurements changes very slowly as the value of the contribution moves away from zero. The statistical uncertainties shown in these Figures are determined based on 70% beam polarization and 30 day runs for the forward asymmetries and for each of the backward asymmetries. The beam polarization is a projection from what is currently available to what we expect to be possible at time the experiment runs.

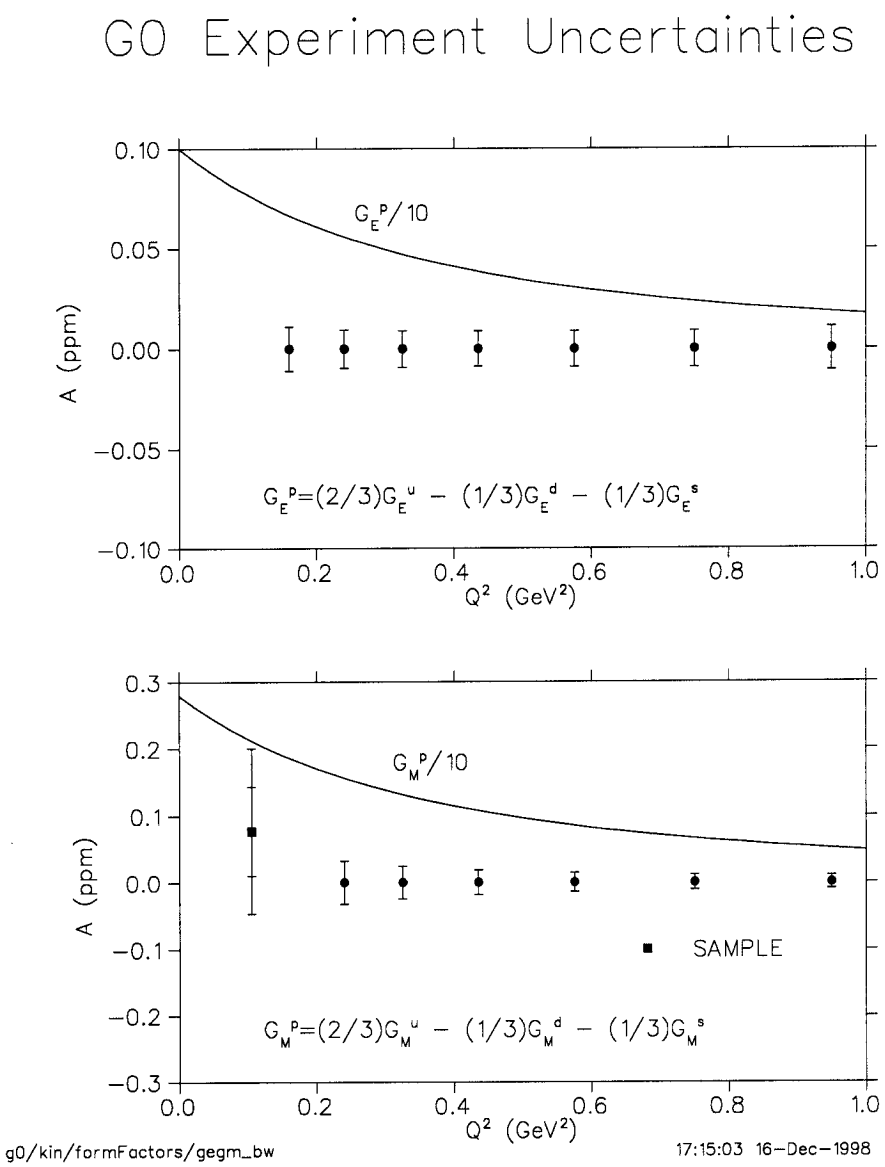
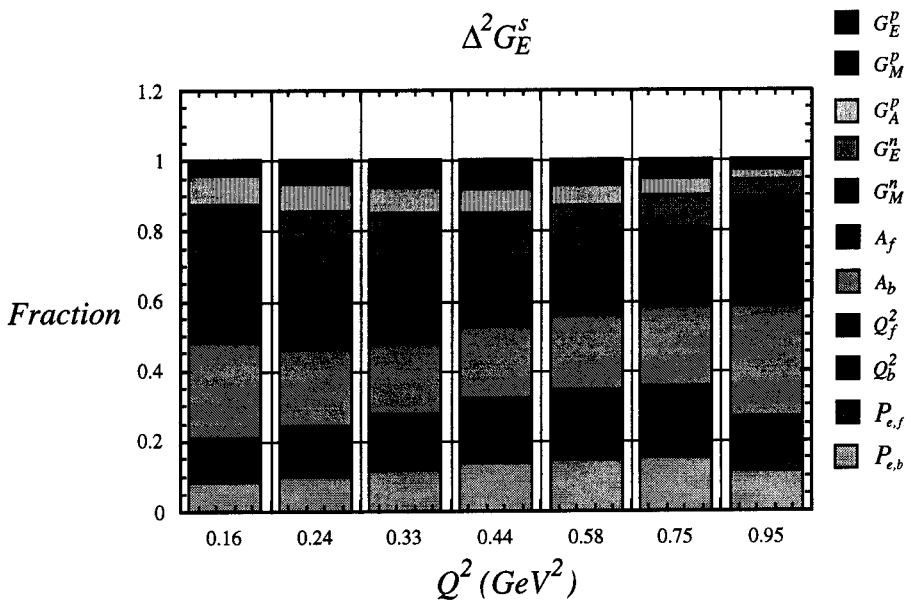


Figure 2.2: Expected results from the G^0 experiment. Overall uncertainties are plotted.

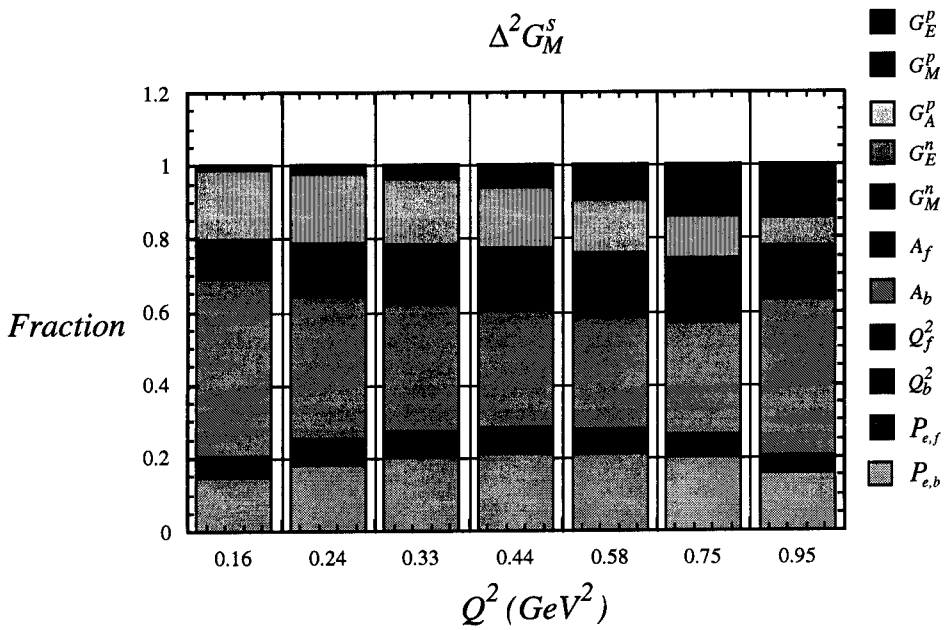


Individual Uncertainties:

$$\frac{\Delta G_E^p}{G_E^p} = 2\% \quad \frac{\Delta G_M^p}{G_M^p} = 2\% \quad \frac{\Delta G_A^p}{G_A^p} = 10\% \quad \frac{\Delta P_b}{P_b} = 2\% \quad T = 700h$$

$$\frac{\Delta G_E^n}{G_E^n} = 20\% \quad \frac{\Delta G_M^n}{G_M^n} = 3\% \quad \frac{\Delta Q^2}{Q^2} = 1\% \quad P_b = 70\%$$

Figure 2.3: Expected contributions of uncertainties in determination of G_E^s from G^0 experiment.



Individual Uncertainties:

$$\frac{\Delta G_E^p}{G_E^p} = 2\% \quad \frac{\Delta G_M^p}{G_M^p} = 2\% \quad \frac{\Delta G_A^p}{G_A^p} = 10\% \quad \frac{\Delta P_b}{P_b} = 2\% \quad T = 700h$$

$$\frac{\Delta G_E^n}{G_E^n} = 20\% \quad \frac{\Delta G_M^n}{G_M^n} = 3\% \quad \frac{\Delta Q^2}{Q^2} = 1\% \quad P_b = 70\%$$

Figure 2.4: Expected contributions of uncertainties in determination of G_M^s from G^0 experiment.

3 Relation to Other Experiments

3.1 HAPPEX

There are a number of differences between the capabilities of the HAPPEX and G^0 experiments. Most importantly, because of the relatively small acceptance of the Hall A spectrometers, the HAPPEX measurement is restricted to forward angle asymmetries. Therefore, no direct extraction of G_E^s and G_M^s is possible in the HAPPEX experiment. Secondly, for the forward angle asymmetries, the statistical precision is limited by the acceptances of the spectrometers. In the case of G^0, forward angle asymmetries will be measured at seven values of momentum transfer *concurrently* as shown in Figure 3.1. The statistical precision shown here is that for the experiment as proposed in 1993 with 49% beam polarization and a 30 day run. For comparison, the published result from the recent HAPPEX run is also shown. The HAPPEX plans for 1999 are to reduce the uncertainties by a factor of two with increased running time and improved polarization. HAPPEX also proposed 4 other forward angle asymmetries at momentum transfers ranging from 0.268 to 1.295 GeV^2. The momentum transfer of the present measurement is slightly below the maximum in the figure-of-merit which drops off by a $\sim$ 30% for each of the extreme values of momentum transfer above.

Even though there is overlap in the approved kinematic ranges of the two experiments, there are clearly significant differences in the instrumentation and techniques for the two measurements. The two measurements are therefore complementary and will provide an important mutual cross check of results.

3.2 Relation to Other PV Measurements

Jefferson Lab has approved parity-violation measurements with both ^{2}H and ^{4}He targets. The ^{2}H measurement proposed in E91-010 is for forward angles and is focussed on strange quark effects. The ^{2}H measurement proposed for the G^0 experiment is a single backward angle measurement at $Q^2 = 0.5$ GeV^2 used to determine the contribution of the axial radiative correction to the asymmetries (this will complement the measurement of a similar quantity at low momentum transfer in the deuterium part of the SAMPLE experiment at Bates).

The approved experiments for ^{4}He are at low momentum transfer ($Q^2 < 0.2$ GeV^2: 91-010) and moderate momentum transfer ($Q^2 = 0.6$ GeV^2: 91-004). These experiments will determine G_E^s in the ^{4}He nucleus and are therefore complementary to direct measurements on the proton.

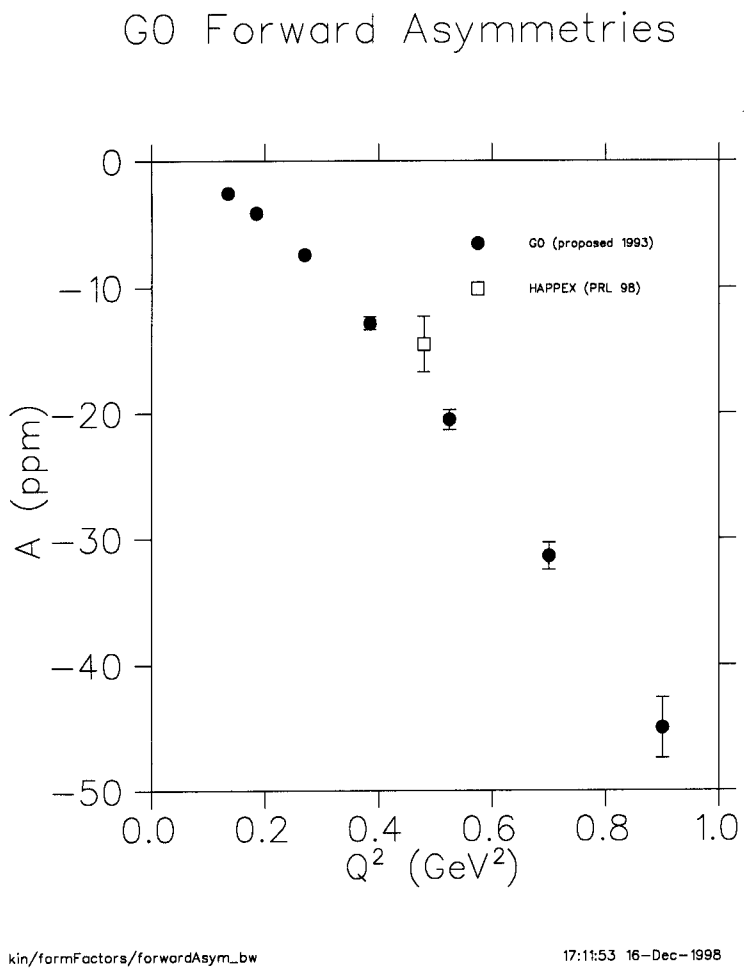


Figure 3.1: Comparison of the G^0 and HAPPEX forward angle asymmetries (see text for details).

3.3 Relation to ϕ Photoproduction

There has been some discussion of the sensitivity of, in particular, polarized ϕ photoproduction [He92, Ti97, Ti98] to test hypotheses of knocking out $\bar{s}s$ pairs from the nucleon (E93-022). Such measurements again provide complementary information as the nucleon matrix elements probed are more complicated overlaps. These also depend to a significant degree on models for their extraction.

4 G^0 Management Organization

The G^0 Management Plan describes the processes and procedures to be used by the Project Manager, the Spokesperson, and the Collaboration to construct, install, and execute the experiment. It includes management organization for both the construction/installation and experiment/physics branches of the project with brief job descriptions for responsible parties. The Management Plan also includes a work plan, a framework for control and oversight of subsystems, a budget with specific contingency guidelines, and a summary of the schedule and manpower resources. A final Management Plan was submitted to DOE and NSF on December 14, 1998.

The G^0 project has been separated into two management structures. One branch is concerned with the construction and installation of the experimental equipment and outlines the responsibilities for tracking budget, schedule and performance. Those responsibilities will begin upon approval of the management plan and they will be phased out when the apparatus has been commissioned in Hall C. The second branch outlines the responsibilities for determining and meeting the physics goals of the experiment including software, design criteria for hardware systems, development runs, running the experiment and analyzing the data. It is envisioned that as the construction and installation phase of G^0 ends, the Experiment & Physics Organizational Chart will expand to include additional responsibilities for hardware subsystem managers such as overseeing ongoing performance and maintenance work.

The Construction & Installation branch of the G^0 management organization specifies responsibilities for getting the experimental hardware installed and working in Hall C. The Project Manager (A. Lung, Jefferson Lab) together with her management team of integration physicist (S. Williamson, UIUC), project management support (G. Smith, Jefferson Lab), and engineering and technical support (W. Schneider, Jefferson Lab) have overall responsibility for execution of the hardware project including cost, schedule and performance control for both Jefferson Lab and outside collaboration groups. The organizational chart for the Construction & Installation branch of the collaboration is shown in Figure 4.1.

A complementary organization of the G^0 collaboration, the Experiment & Physics Organization, has the responsibility of providing the necessary physics input to the design of the apparatus, as well as for commissioning the equipment after it is installed, and for the execution of the experimental program. During the construction and installation stage, one of the primary activities of this branch will be to provide advice based on physics considerations to those involved in construction, and to insure through careful monitoring of the design that the apparatus will be capable of carrying out the experimental program.

The organizational chart depicted in Figure 4.2 illustrates the division of responsibility and lines of communication in the Experiment/Physics Organization. Additional information about the role of the Spokesperson and the Executive Committee within the collaboration can be found in the G^0 Collaboration Governance document [G098]. Table 4.1 lists the

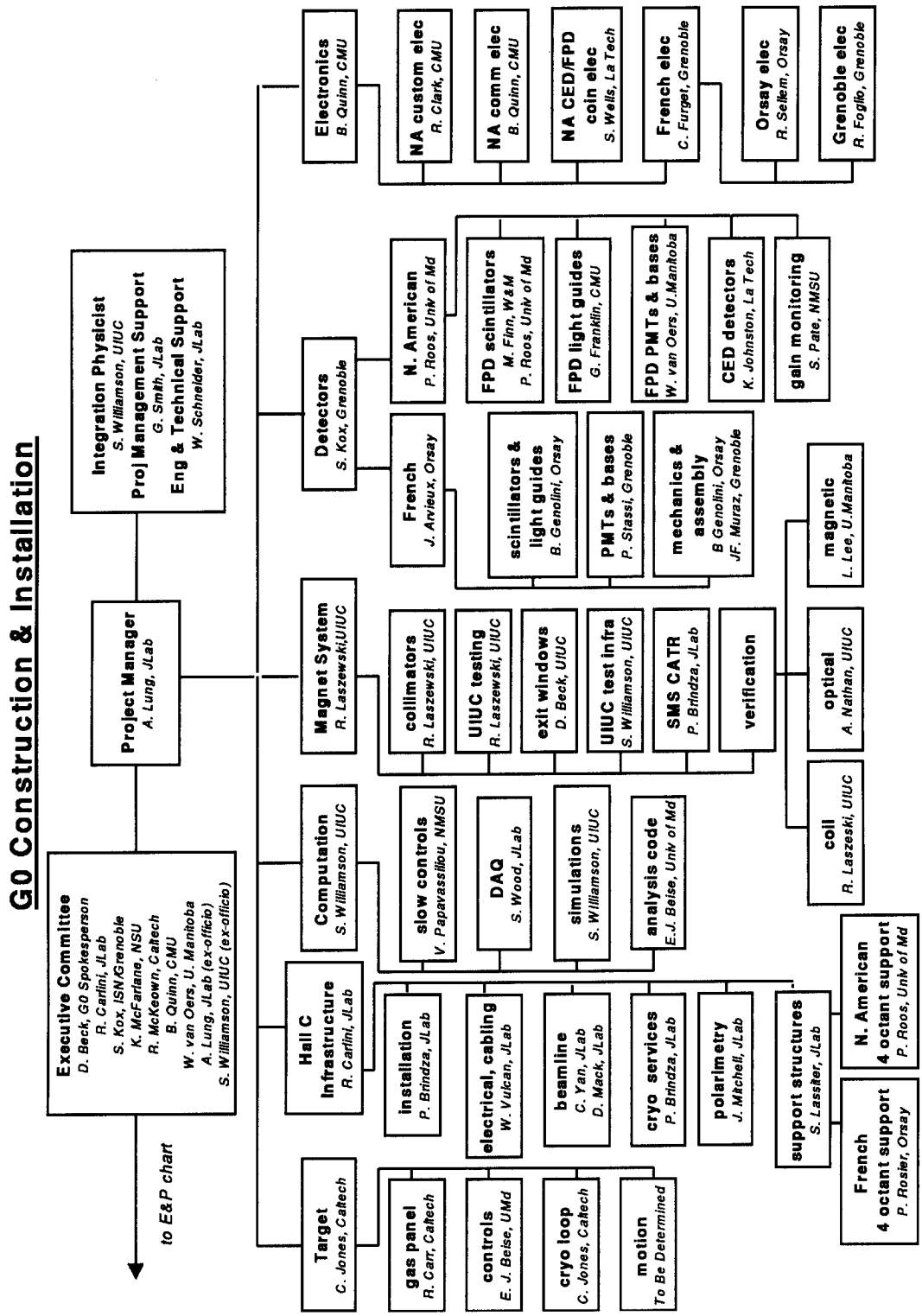


Figure 4.1: Organizational chart for management of G^0 construction and installation. E&P stands for Experiment & Physics organizational chart (Figure 4.2)

Task	Responsible Institutions
Overall Coordination	TJNAF, University of Illinois
Superconducting Magnet System	TJNAF, TRIUMF, University of Manitoba, University of Illinois
Detectors	
N. A. Focal Plane Detectors	Carnegie-Mellon University, College of William and Mary, Hampton University, TRIUMF University of Manitoba, University of Maryland, University of Northern British Columbia
French Focal Plane Detectors	IPN-Orsay, ISN-Grenoble
Cryostat Exit Detectors (CEDs)	Louisiana Tech. Univ.
Gain and Timing Monitoring	New Mexico State University
Electronics	
N. A. Electronics	Carnegie-Mellon University
French Electronics	IPN-Orsay, ISN-Grenoble
CED Electronics	Louisiana Tech. Univ.
Computation	
Slow Controls	New Mexico State University
Data Acquisition	IPN-Orsay, ISN-Grenoble, North Carolina A&T State University, TJNAF
Analysis Software	University of Maryland
Simulation	IPN-Orsay, ISN-Grenoble, American University, North Carolina A&T State University, University of Illinois
Target	California Institute of Technology University of Maryland
Infrastructure	
Hall C Systems	North Carolina A&T State University, TJNAF
Polarized Source	TJNAF, Virginia Tech
Theory Support	University of Connecticut, University of Massachusetts

Table 4.1: The major responsibilities for provision of manpower and equipment for the G^0 experiment is divided among the collaborating institutions as indicated above.

collaboration institutions, which have committed to provide manpower and equipment associated with various subsystems of G^0. The organizational charts Figures 4.1 and 4.2) summarize individuals who lead the efforts to provide hardware and software systems. The G^0 Collaboration consists of 83 physicists from 19 institutions. Each member is responsible for contributing to the design, construction, and commissioning of the G^0 instrumentation, and for executing the experiment. Table 1.1 lists all current members of the G^0 collaboration.

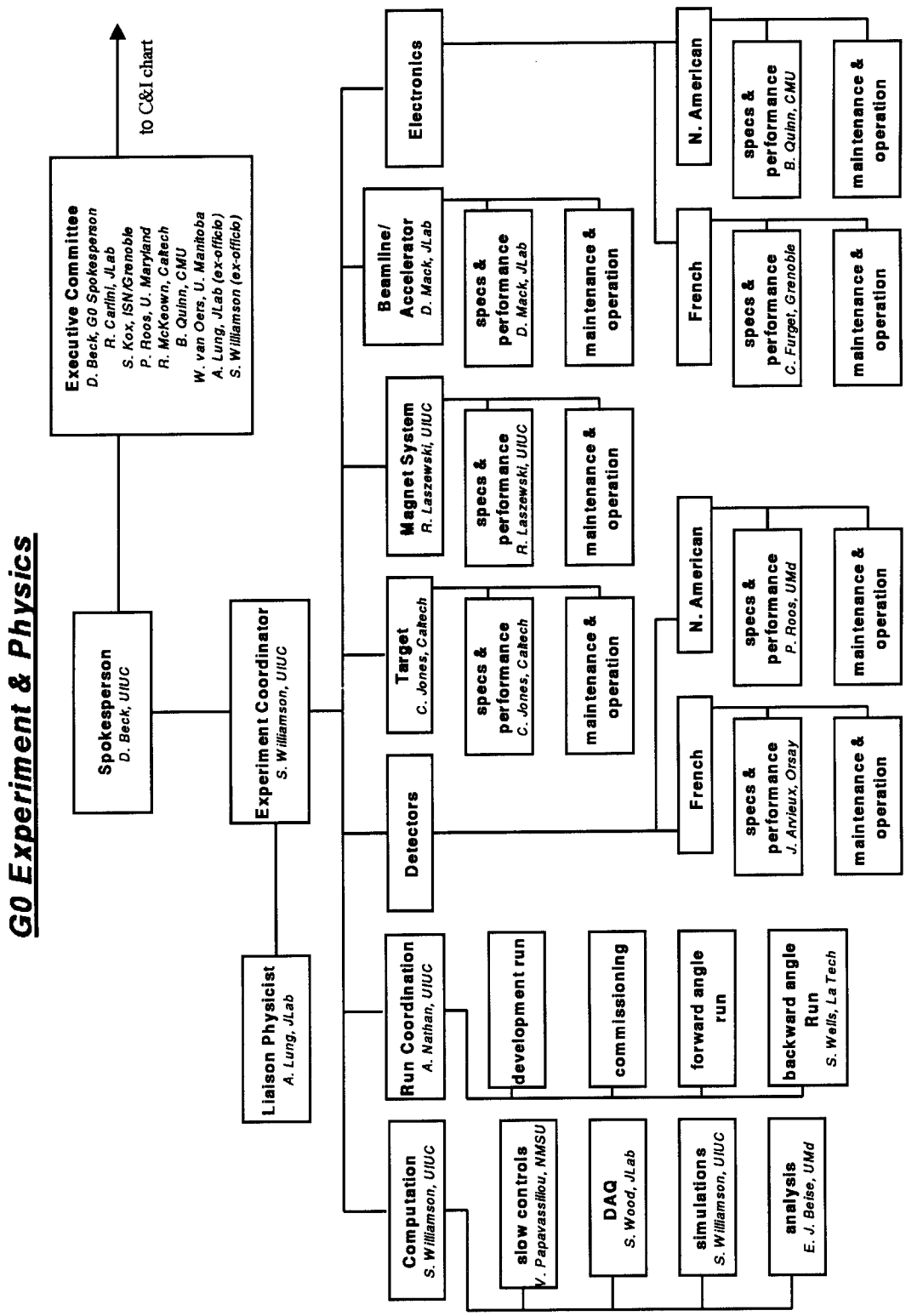


Figure 4.2: Organizational chart for management of G^0 physics and the experiment. C&I stands for Construction & Installation organizational chart (Figure 4.1)

WBS	Item	Equp. ($k)	Cont. ($k)	Total ($k)	Spent/ Contracted ($k)	Funding Source ($k)
1	ISMS	2902	553	3455	2456 NSF 150 DOE/JLab	2079 NSF/G^0 710 NSF/NPL 493 new NSF/G^0 173 DOE/JLab
2	Detectors	292	57	349	110 DOE/JLab	349 DOE/JLab
3	Electronics	361	39	400	22 CMU	362 DOE/JLab 38 CMU
4	Computation	0	0	0	0	
5	Target	227	62	289	32 NSF/Caltech	171 NSF/G^0 41 NSF Caltech 77 DOE/JLab
6	Hall C Infrastructure	1836	451	2287	140 DOE/JLab	2287 DOE/JLab
G^0 TOTALS		**5618**	**1162**	**6780**		**2250 NSF/G0** **710 NSF/NPL** **38 CMU/DOE** **41 Caltech/NSF** **493 new NSF/G0** **3019 new DOE/JLab** **229 Univ grants**

Table 4.2: Summary of G^0 budget for items in each major subsystem which are funded through DOE and NSF. All figures are estimated in FY98 dollars.

A summary table of the budget estimates for each major subsystem is shown in Table 4.2. Note that only the DOE and NSF funded portions of the experiment are included here. The significant contributions from the Canadian (NSERC funding) and French (ISN/IN2P3 funding) collaborators are described in scope in their respective MOUs, rather than in dollars. The total G^0 cost estimate for DOE and NSF funding is $6780k. In order to demonstrate their commitment to G^0, collaborators from institutions with ongoing DOE and NSF grants have pledged an additional $229k over the next three years. A summary of the funding sources, both previously committed and new requests, is shown in Table 4.3. Accounting for the previously committed funding from NSF grants to the University of Illinois and to Caltech, and from a DOE grant to Carnegie Mellon University, and the new commitment of $229k from ongoing grants, the outstanding requirement for new funding total is $3512k. An agreement has been reached between NSF, DOE and Jefferson Lab to provide the new funding identified in Tables 4.2 and 4.3. The funding profile generated as part of this agreement is shown in Figure 4.3.

The schedule for the G^0 project was developed using standard project management techniques and is based on planning sheets and milestones submitted by subsystem managers.

"Funds Committed for G^0"	
NSF/G^0 grant to UIUC	\$2250 k
NSF/UIUC/NPL grant	\$710 k
NSF/Caltech grant	\$41 k
DOE/CMU grant	\$38 k
Additional contributions from ongoing grants: DOE(CMU and NMSU) and NSF(UIUC, Caltech, UMd, W&M, LaTech)	\$229 k
"Additional New Money"	
DOE and/or NSF	\$3512 k
G^0 DOE/NSF Budget Total:	**\$6780 k**

Table 4.3: Table of DOE and NSF funding sources for the G^0experiment. They are broken down into funds which had been committed as of July 1998, and the additional funds required to complete the project. All figures estimated in FY98 dollars.

The principal constraints on the overall schedule are the need to integrate the major subsystems in a reasonable order and the final funding profile as shown in Figure 4.3. A summary of the major milestones for subsystem completion, integration and installation is shown in Table 4.4. Currently, tasks on the critical path include the design and fabrication of the detector support, the assembly and testing of the detector modules, and the installation of components of the experiment in Hall C.

G^0 Major Milestones

WBS	Milestone	Agency	FY Date
1.3.4	Magnet Final Design Review	NSF	Q1 '99
1.3.15	Magnet delivery to UIUC	NSF	Q4 '99
1.12	Magnet acceptance testing at UIUC complete	NSF	Q1 '00
1.3.20	Magnet delivery to JLab	NSF	Q4 '00
6.1.1.5.3	Magnet installation in Hall C	DOE	Q3 '01
2.1.5.8	NA FPD detector assembly begins	DOE	Q2 '00
2.1.7	NA FPD assembled/installed in octants	DOE	Q3 '00
2.2.7	CED delivery to JLab	DOE	Q4 '00
2.1.8.2	NA FPD floor testing complete	DOE	Q1 '01
2.5.9	French FPD delivered to JLab	IN2P3	Q3 '01
2.3.18	GMS installed on all NA & French FPD	DOE	Q3 '01
2.5.11	French FPD floor testing complete	IN2P3/DOE	Q3 '01
6.1.1.7.5	FPD Octants installed in Hall C G^0 frame	DOE	Q3 '01
2.1.10	Integrated testing of all FPD in G^0 frame	DOE	Q3 '01
3.1.6	Comparative testing of electronics solutions	IN2P3/DOE	Q2 '99
3.2.3	Finalize design for French electronics	IN2P3	Q2 '99
3.1.1.5	NA custom boards delivered to JLab	DOE	Q3 '99
3.2.4	Delivery French electronics to JLab	IN2P3	Q2 '00
3.1.2.8	NA commercial boards all delivered to JLab	DOE	Q1 '01
3.1.4.2	Integrated testing NA elec with NA detectors	DOE	Q1 '01
3.4	Electronics installation/testing complete	IN2P3/DOE	Q1 '01
3.1.3.9	CED electronics delivered to JLab	DOE	Q1 '01
4.2.4.2	Production CODA system installed & running	DOE	Q2 '01
4.1.5	Install & test slow controls at JLab	DOE	Q3 '01
5.7	Target fabrication complete	NSF	Q1 '00
5.8.4	Target testing at UIUC complete	NSF	Q2 '00
5.9	Target delivery to JLab	NSF	Q3 '00
6.1.1.6.2	Target installation in Hall C	DOE	Q3 '01
6.1.1.1.2	Finalize design Hall C layout	DOE	Q1 '99
6.6.1.5	Award bid for octant support	DOE	Q3 '99
6.6.4.5	Award bid for ferris wheel	DOE	Q3 '99
6.6.3.5	Award bid for CED octant support	DOE	Q1 '00
6.1.1.7.3	Ferris wheel installed	DOE	Q3 '01
6.1.1.10	G^0 installation complete	DOE	Q3 '01

Table 4.4: Major milestones for G^0 by subsystem with expected completion date by fiscal year (FY) quarters. These form the baseline schedule for the G^0 project.

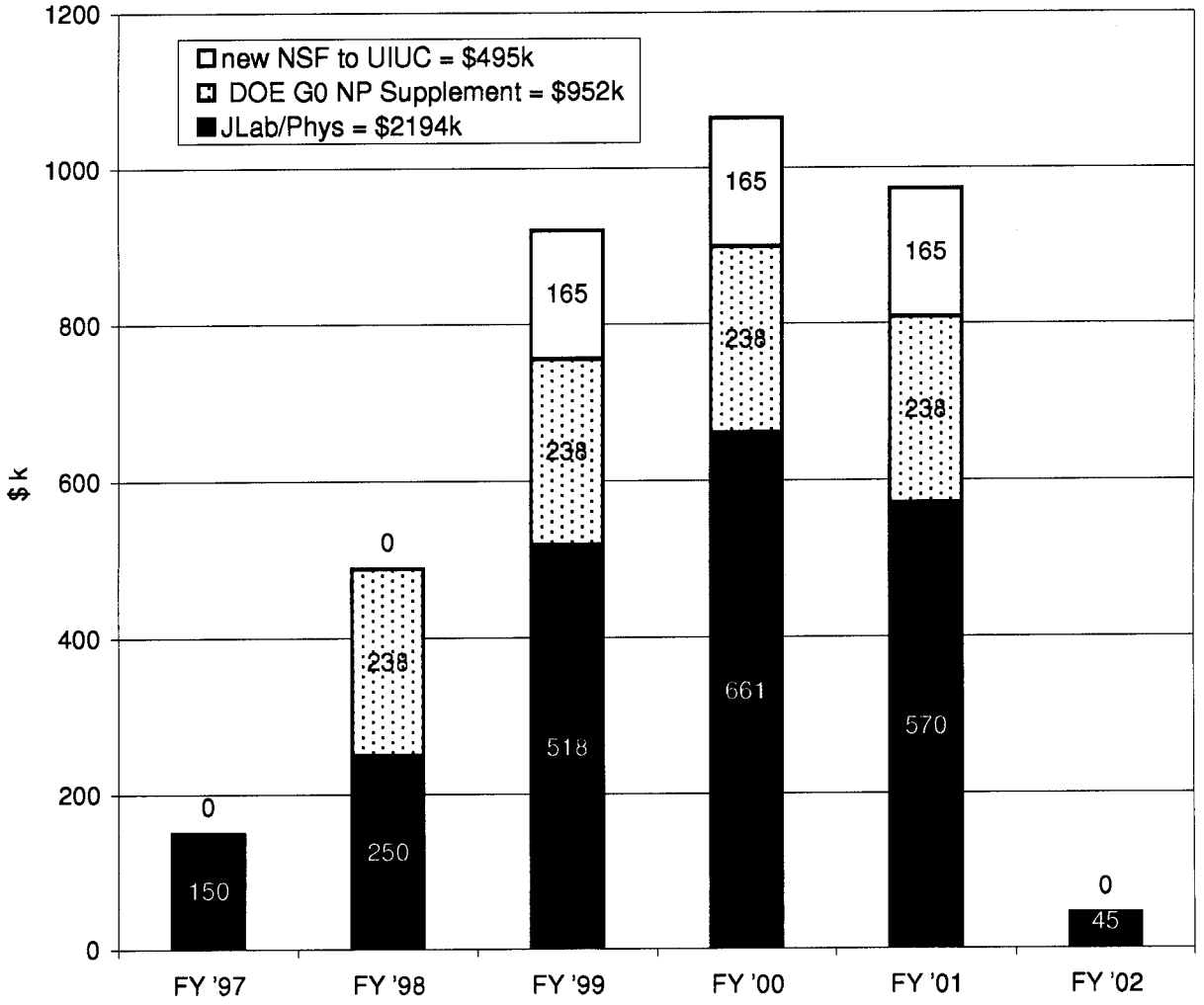


Figure 4.3: G^0 Funding Profile: "new funds" in actual year dollars; overhead subtracted on DOE funds.

5 Subsystem Descriptions and Progress

5.1 Introduction

In the following sections, brief descriptions and updates on progress from the subsystem managers (see Figure 4.1) are presented.

5.2 Integrated Superconducting Magnet Subsystem

The integrated superconducting magnet system (ISMS) consists of the superconducting toroidal magnet which has been contracted to BWXT, the internal collimation and shielding modules which were designed and fabricated by UIUC, and a number of related projects that either interface directly with the magnet (vacuum windows, support carriage, external shielding), or else are required for performance verification and for final acceptance testing at UIUC.

5.2.1 Superconducting Toroid (BWXT)

The contract for the construction of the G^0 superconducting toroid was awarded to BWXT on 8 May 1997. To date, the eight coils of the magnet have been assembled and essentially all of the cold-mass hardware has been fabricated. Work required for the acceptance testing of the coils is in progress. Following coil acceptance, it is expected that the assembly of the cold-mass will proceed through Q2, 1999. Fabrication of the magnet vacuum-vessel has moved onto the critical path, and there are material-selection issues that have yet to be resolved. If these issues can be finalized in a timely way, the complete system assembly and factory testing will proceed through Q3, 1999 and installation at UIUC will occur at the end of Q4, 1999. Final acceptance testing and various system trials will proceed through the year 2000. Installation at Jlab is not scheduled until Q3, 2001.

5.2.2 Collimation and Shielding Modules (UIUC)

The eight Collimator Modules nest between the coils of the toroidal magnet and define the acceptance of the spectrometer as well as provide line-of-sight shielding between the target and the (external) detector array. Each module weighs about 4 tons, and is fabricated from aluminum and a special alloy of Pb. The engineering design and prototyping tests were completed in 1997, and the procurement of major components by competitive bidding began in January of 1998. The assembly of the first module at UIUC was completed on 29 June 1998, and BWXT was notified of its availability. Because BWXT was not prepared to assemble the cold-mass at that time, it was possible to reduce the over-all cost and risk of shipping by sending the modules in two groups. Four modules were completed by the end of August 1998; they were shipped to BWXT on 30 September, arriving 2 October.

The second set of four were completed on 23 October, and shipped 4 November, arriving 6 November 1998. All eight collimator modules arrived without incident, and the work was completed one month ahead of schedule.

5.2.3 Carriage (UIUC)

The major structural components of the Vessel support carriage were procured in June 1997. Fabrication of the minor components in the NPL machine shop will be completed in early 1999. Actual assembly of the carriage is a low priority, and will be managed by UIUC technicians in the first half of 1999. It is likely that some modification of the carriage design will be required by ongoing changes in the hall-C installation plan at Jlab.

5.2.4 Vacuum Windows (UIUC)

The engineering design of the particle exit-windows is in its initial stages. The present concept is that a titanium window with a thickness in the range 0.016" to 0.020" will be employed. Issues of material properties, safety implications, fabrication techniques, and material availability are under investigation. It is anticipated that the design, prototyping and testing, and procurement will proceed through 1999. The actual fabricated windows will not be required until the spectrometer is installed at Jlab in 2001.

5.2.5 External Shielding Collar (UIUC)

The final engineering design of the external Pb shielding-collar will proceed once the design of the downstream cryostat-head, to which it attaches, is finalized. The fabrication techniques will be those employed in the manufacture of the Pb components of the collimator modules. The actual collar assembly will not be required until the spectrometer is installed at Jlab in 2001.

5.2.6 Optical Verification (UIUC)

The Optical Verification procedure will measure the locations of the coils and collimator modules as assembled in the cryostat vessel, at BWXT. The measurement will be made at 80K (LN2) at which temperature most of the ultimate thermal contraction will have taken place. The purpose of the test is to identify any necessary modifications to the assembly before the magnet leaves the factory. The Optical Verification will employ video photogrammetry, and requires the fabrication of eight window-boxes, each with three viewing ports, which will be installed over the cryostat exit-window apertures. The engineering design of the window-boxes has been completed, and procurement will begin in January 1999. Prototyping of the viewing port design is in progress. Each port consists of a central optically-flat camera-window isolated within a concentric Lucite flash-window. The viewing ports will be manufactured at UIUC/NPL in early 1999. It is expected that the ports and window boxes will be assembled and vacuum tested at UIUC in Q2, 1999.

5.2.7 Magnetic Verification (TRIUMF/ UIUC)

The Magnetic Verification test is critical for establishing, under full operating conditions, that the toroid meets specified quantitative structural tolerances which reflect directly on its performance as a spectrometer. It is an integral part of the magnet acceptance procedure at UIUC. The instrumentation for measuring zero-crossings in components of the magnetic field external to the cryostat vessel will be fabricated by the TRIUMF group. Conceptual designs have been investigated, and detailed engineering design work and fabrication will proceed when the issue of vessel material has been resolved. It is anticipated that operational magnetic-verification instrumentation will be needed for final acceptance testing in Q1, 2000.

5.2.8 NPL Infrastructure (UIUC)

Work is proceeding on bringing the NPL Helium Liquefier into full operation. It is expected that an extended test run of the system will take place in Q1, 1999. Design and fabrication of cryogenic transfer lines is dependent on decisions that will be made about G^0 cryolines for Jlab Hall-C and the degree of overlap between the two that can be exploited to reduce overall costs.

5.3 Target Subsystem

The G^0 experiment will use a 20 cm long liquid hydrogen target which is axially symmetric about the beam direction. The construction of the target is the responsibility of groups at Caltech and the University of Maryland.

Significant progress has been made in the last year on the design and fabrication of the cryogenic target loop. Because relatively low energy protons ($\geq$ 50 MeV) exiting the target at $\sim 70°$ are detected in the forward angle measurement, the amount of material in the path of outgoing particles must be minimized. Several target cells have been fabricated with wall and endcap thickness of $7 + / - 1$ mil. The cells did not fail in hydrostatic burst tests up to pressures of 140 psi, although some deformation of the endcap occurred between 100 and 140 psi. These tests verify that our cells, which will be tested to 100 psi before being incorporated into the cryotarget, are rated over a factor of two above the maximum pressure in the target during a catastrophic vacuum failure of the surrounding vacuum vessel while the target is full of liquid hydrogen. The flow manifold, hydrogen cell and helium cell have been constructed at Caltech. We have received the target heat exchanger, which was built by a commercial firm. We are now in the process of finalizing the design of the liquid hydrogen pump, the one major component of the cryoloop left to be built.

Other parts of the target group's responsibilities include the the gas handling system, which is designed to automatically relieve pressure in the system in the event of target boiling; the monitoring and controls hardware and software to read and record temperatures and pressures, set and record coolant flow to the heat exchanger, monitor the performance of the liquid hydrogen pump, and control the heaters to maintain constant heat load on the

cryoloop; the interlock system, which is a hard-wired system designed to prevent hazardous situations from arising; and the transverse motion mechanism to align the target in the beamline. Varying degrees of progress have been made on these parts of the target system. The target gas handling system has been completely designed and all the components specified. All hardware for the monitor/control system has been specified, a number of the modules have been purchased and tested, and substantial progress has been made in writing and testing a PC-based LabView program to control devices and read, record, and display the target data. The service module, which is the vacuum vessel that houses the target support and gas and electrical feedlines and interfaces the beamline to the magnet, is not currently the responsibility of the target group. As no group has assumed responsibility for this device since it was dropped from lab infrastructure in Feb. 1998, the Caltech group has recently begun to work on a design, with input from JLab and UMd. It is likely that Caltech and/or UMd will assume responsibility for the service module should the design be approved and the money to construct the vessel in the DOE Equipment budget be sufficient to cover its cost. The design of the target alignment mechanism is also in a preliminary stage, as it must necessarily proceed in parallel with the design of the service module.

A list of milestones for the target were identified as part of the G^0 Management Plan. These are the completion of fabrication of the cryogenic target loop, the completion of target tests at UIUC, and the delivery of the target system to JLab.

The G^0 target underwent a Preliminary Design Review of the target cell, cryoloop, gas handling system, interlocks, and monitor/controls system at JLab on Dec. 7-8, 1998. These parts of the target system were reviewed by a panel of technical experts from the laboratory and John Mark, an expert on cryogenic targets and safety who worked for years at SLAC. Based upon valuable technical discussions with the panel members, the target group is making several changes to improve target performance and reliability. The outcome of the review was that all technical designs presented were approved. Although the service module was not within the scope of the review, they understandably expressed concern about its design, asking that the issue of target alignment be solved in detail and that the service module design proceed directly. They also specified that the G^0 target be kept a "Class 0" installation as classified by the Hazard Gas Standards for the lab, which requires that the total inventory of hydrogen in the hall be ≤ 600 g, and that the target group and the G^0 Project Manager identify sources for all items required to install and operate the G^0 target in Hall C. While the design of the hardware and software for the target monitor/control system was found to be sound, the Preliminary Design Review committee raised an issue concerning the use of LabView software instead of EPICS, which is currently used for the Hall C and A cryotarget monitor and control systems. This issue will have to be resolved before the monitor/control system can be completed or the experiment scheduled.

5.4 Detector Subsystem

5.4.1 North American Detectors

The G^0 spectrometer is composed or eight octants of detectors which will count recoil protons from small angle e-p scattering (initial orientation of the spectrometer) or scattered electrons from large angle e-p scattering (180° rotation of the spectrometer). Four of the octants will be built by a North American collaboration, and the other four by a French collaboration (ISN-Grenoble and IPN-Orsay). Each octant will consist of 16 pairs of plastic scintillation counters defining a specific range of Q^2. The first 15 detector pairs measure Q^2 values of the recoil proton ranging from 0.12 to 0.55 $(GeV/c)^2$. The upper detectors serve double duty in that they are also used to detect recoil protons with Q^2 values from 0.55 to 1.0 $(GeV/c)^2$. These protons from smaller recoil polar angles strike detectors 12-15, and can be separated via their time-of-flight. The 16th detector serves as a "guard ring", and can also be used to check the proper setting of the field for the spectrometer. The azimuthal acceptance of the detectors for each octant is limited by the upstream collimators to lie between $\phi = \pm 10°$.

5.4.1.1 FPD detectors

The shapes of the detectors are circular and are based on an array of proton rays traced using the TOSCA program. Rays were generated for 16 values of Q^2 corresponding to the detector boundaries, three target positions representing the front, center, and rear of the target, and three azimuthal angles of 0° (center of the octant), 5°, and 10.5° (one-half degree beyond the limiting aperture of perfectly aligned collimators). Those rays were used to determine the plane of each counter by their intersection with the focal surface (as defined in the G^0 TDR and R. Laszewski's notes). The circular shape of each detector, both upper and lower boundary, was then found from the intersection of the rays from the center of the target and azimuthal angles of 0°, 5°, 10.5° with the detector plane. The lengths (azimuthal extent) of the counters were determined with rays from the rear of the target at 10.5°, rays which have to maximum extent in y (including misalignment of the upstream collimators). Having determined this length, the detector was extended to account for multiple scattering from the azimuthal collimators. The design and definition of the focal plane detectors has largely been the work of K. McFarlane, previously a faculty member at Norfolk State and now at Hampton University.

A concern related to the length of the detectors, was the possibility that multiple scattering of polarized protons (from spin transfer) from the collimators might create a false asymmetry. This effect was numerically simulated (Cowley, UMd, JLab, and Stellenbosch U) using phenomenological optical model potentials for lead, and although the concern is justified, an extension of the length of the detectors is of no consequence.

The above is the general description for the definition of the most of the detector shapes. However, exceptions exist. For example, the upper boundaries of detectors 14, 15 and 16 have been modified for acceptance purposes. In addition an interference problem with the lead shielding, providing line of sight shielding from the target, required that the first three

detectors be moved back to somewhat larger z. By doing so, we maintain a minimum of 10 cm of lead shielding (16 cm in most cases) with minimal impact on the Q^2 resolution.

The final shapes are now defined and DXF files created to cut the scintillator material in both the U.S. and France. Based on the energy loss of the protons, we have chosen to use 5 mm thick scintillator for the lowest Q^2 points (first 4 detectors) and 1 cm scintillator for the remaining detectors. The scintillator material, Bicron BC-408, for the four North American octants has been ordered and delivered to Jefferson Lab. We expect to have the scintillator shapes (slightly oversized) cut by water jet in January, with final machining to follow as soon as possible thereafter. The polishing of the scintillator material is expected to begin in the spring and be finished by the end of the summer of 1999. Upon completion the scintillator will be wrapped in aluminized mylar "tape", fabricated by a device designed and constructed by the U. Maryland group.

5.4.1.2 UVT Light Guides

In the interest of redundancy the North American collaboration has decided to view each end of each scintillator with a photomultiplier tube (four PMTs per scintillator pair). This decision has led to a high density of light guide material in the region on each side of the FPDs. As a result a great deal of design time has been invested in removing interferences between the various components, and it has been necessary to use thinner than optimum light guide material for the intermediate Q^2 detectors (0.375" thick for 1 cm scintillators). The limited space has also necessitated the use of rather sharp 90° bends in the light guides (radii of 3-5 cm). Finally the large magnetic fringe fields have necessitated the use of rather long light guides to transport the light from the scintillators to the photomultiplier tubes (approximately 1.8 m for the lowest Q^2 scintillators).

The decisions above led to concerns about the amount of light reaching the photomultiplier tubes, and a number of studies of the light transmission properties of light guides (both experimental and theoretical) have been carried out over the past year. These are discussed below. However, based on these studies we believe that we have a viable design, and ordered the UVT light guide material (Bicron BC-800). All material is now at Jefferson Lab.

5.4.1.3 Photomultiplier Tubes, Bases and Housings

The necessary photomultiplier tubes for the four octants being constructed the North American collaboration have been delivered. The tubes are 12-stage Phillips XP-2262B. All 300 tubes have been tested for linearity and their gains measured. A selection of the tubes were tested in more detail; for example, for count rate capability (in conjunction with the chosen base design). All tubes have a bar code identification.

The tube bases have been designed and built by TRIUMF/University of Manitoba and are completed. The base design was iterated several times in the collaboration, because of the dynamic range required by the experiment (minimum ionizing electrons to 60 MeV protons), and the rather high gain of the specific tubes chosen. The bases are passive, being comprised of resistors and zener diodes.

The plastic housings holding the tubes (a spring loaded design) have also been designed and are being fabricated at TRIUMF. Although the tubes sit in a low magnetic field environment, studies of the tube-base combination showed rather strong sensitivity to magnetic field. Therefore special care has been taken to ensure that the magnetic shielding fully covers the phototube.

5.4.1.4 Prototype Studies

A variety of prototypes have been fabricated and tested in preparation for the actual construction. These prototype studies have been extremely beneficial, particularly in terms of the "do nots" associated with the construction. Scintillators corresponding approximately to the No. 8 and No. 15 scintillators have been constructed. In doing so the methods for water jet cutting, machining, and polishing were developed. Several studies of the light output (absolute) versus position using cosmic rays and a beta source have been carried out for a variety of surface treatments and light guide shapes. These continue and include studies of the time structure of the pulses. Various components of this work have been been carried out by the Norfolk State, William and Mary, and U. Maryland groups. A series of similar important tests are now proceeding in France.

As noted above we had concerns about the amount of light reaching the photomultiplier tubes. Therefore prototype light guides were fabricated at Carnegie-Mellon (C-M is responsible for producing the full complement of light guides) and extensive transmission studies of these guides carried out by C-M and by the U. Maryland group. These studies have been compared to numerical simulations (GUIDEIT), and the agreement is quite good, lending confidence to the numerical simulations. Based on these studies of the prototypes we believe that the methods of construction are adequate to produce the required light.

A prototype support structure for one pair of scintillators (No. 8) has also been constructed, and is being assembled and tested at William and Mary. ¿From this we have learned valuable lessons on specification of all components, the necessity of some adjustment features, and procedures for glueing the scintillators to the light guides. We will also be able to test methods for light sealing the box. Currently we are using the prototype for additional studies of scintillator-light guide combination.

5.4.1.5 Gain Monitoring System

The stability of the gain and timing of the phototubes, as well as the transmission characteristics of the scintillator-light guide combination, will be monitored by flashing UV laser light directly into the scintillator. This will be done with a nitrogen laser, optical fibers, and a rotating mask allowing the illumination of a subset of fibers at a specified rate. A single fiber mounted at each end of the detector support structure will illuminate a pair of scintillators associated with a Q^2 range. The ends will be alternately illuminated. This system has been designed and the components selected by the NMSU group. Construction of the system awaits funding to purchase the components. Construction will include the necessary fibers to pulse the detectors all eight octants, including the four octants being constructed in France.

5.4.1.6 Detector Support Structure

The FPD support structure for each octant is comprised of a "light tight box" using a tedlar-mylar sandwich as the covering. A preliminary design exists and work is now underway to finalize the design with the finalized detector/light guide design. For the North American octants this support structure will also serve as the "alignment fixture" for glueing the scintillators to the light guides and so attention to the details of adjustment will be required. We expect the design of this to take several more months, and should be completed in March.

5.4.2 French Detectors

5.4.2.1 FPD detectors

The French collaboration will build half of the FPD detectors (4 octants), including scintillators, light guides, phototubes (PMT) and read-out electronics. The CED will be built by the NA for the 8 octants.

The shapes based on TOSCA4, as given by the NA, have been checked independently with 2 different ray-tracing programs by E. Rollinde/P. Vernin and F. Merchez. They are considered as secure and will be taken as a basis for the final design. One remaining question is the overall length of the detectors which is only defined to $\pm$ 2cm at this time.

Scintillators tested included ZA236 and BC408. The former is faster but has a larger attenuation than the latter, so BC408 will be adopted for "long" scintillators 5-16 but ZA236 remains an option for 5mm thick "short" ones 1-4.

The following BC408 prototypes have been ordered to CERN and delivered:

16 (length=1400 mm, thickness=10 mm)

9 (length=740 mm, thickness=10 mm)

1 (length=400 mm, thickness=5 and 10 mm).

They are all equipped with 12 mm thick light guides with fish-tail ending.

Moreover, 2 small scintillators (10 mm thick, 20x20 mm^2) have been built and tested by the IPN-Orsay group in a 800 MeV electron beam at MAMI-Mainz (Dec. 5-6, 1998) in order to measure the number of photo-electrons (results are being analyzed). During the same run, the Disc/Mean-Timer of the IPN-Orsay electronics scheme has also been tested satisfactorily.

New dedicated labs have been installed at ISN-Grenoble and IPN-Orsay for G^0 prototype testing using radioactive sources and cosmic rays. Dedicated data acquisition systems have been set-up in both labs. Measurement of prototype # 9 will start at IPN-Orsay Dec.14, 1998.

For mass production of both detectors and light-guides the French collaboration is still looking at alternative solutions: CERN, Bicron (through its French subsidiary Eurysis) or smaller local firms. We are awaiting price quotes.

5.4.2.2 PMTs and Bases

The French part of the collaboration has decided, like the North American part, on a reading with one PMT at each end of a scintillator plane (4 PMTs for 2 consecutive scintillators in coincidence). The preselected PMTs are Philips XP2282 (8 dynodes) or EMI (10 dynodes) against 12 dynodes for the Philips XP2262 chosen by the NA group. It will be equipped with a X10 transistorized amplifier housed in the base mounting. The rationale is that there is a large dynamic range between the proton detection which lose up to 10 MeV for the forward angles measurement and the minimum ionizing particles which lose only 2 MeV in a 10 mm thick scintillator for the backward electron measurements. By working always at the optimal PMT current, we therefore hope to increase the PMT lifetime. Tenders have been sent and 280 PMTs will be ordered before the end of 1998.

The transistorized base has been developed at ISN-Grenoble. Design has been checked and prototypes are being currently tested for gain stability with a laser. Mass production will follow the final choice of PMTs.

5.4.2.3 Other Issues

There are still a number of issues that are considered important and which have not yet received our full attention. Here is a non-exhaustive list:

- coupling of light-guide to scintillator (glue or optical grease) which may have a consequence on the conditions of transportation between France and the USA
- wrapping, tightness to light
- shielding to low energy particles between 2 consecutive detector planes
- radiation hardness

One important issue is the lack of progress of the mechanics which has been hindered by the uncertainties on the shape (until recently) and length (still pending) of scintillators.

We hope that a realistic schedule for the French detectors can be given at the time of the PAC.

5.4.3 Cryostat Exit Detectors

The cryostat exit detectors necessary for the measurement of large angle electron scattering (requiring 180° rotation of the spectrometer) for all eight octants will be designed and constructed by the North American component of the collaboration. The design and construction of the CEDs is primarily the responsibility of the Louisiana Tech group. (They are currently having discussions with the TRIUMF Scintillator shop concerning the construction of some components.) The detector system will utilize 12 of the 16 Focal Plane detectors (the first four FPDs will not be used) in coincidence with a set of nine new detectors mounted just beyond the cryostat exit windows. These detectors will be viewed by photomultiplier tubes removed from the second scintillator of each FPD pair. As of this writing, the shapes of the CED scintillators are defined and work is in progress designing the light guides and simulating the expected light output. It is expected that the CED design will be completed by the end of January.

5.5 Electronics Subsystem

The electronics for G^0 can be broadly grouped into three classes: monitoring, forward-angle, and back-angle. Of these, the monitoring electronics is the most conventional, consisting of commercial FASTBUS ADCs and TDCs which will collect information from all PMTs in the detector for a small fraction of the beam bursts. The principle function of the forward-angle electronics is to accumulate time-of-flight spectra for each of the focal-plane detectors, allowing elastically scattered protons to be separated from inelastic background. The principle function of the back angle electronics is to count the coincidences between individual focal plane detectors and associated cryostat exit detector elements, permitting separate accumulation of electrons from elastic and inelastic kinematic regions.

Because the monitoring electronics is conventional, relatively little work has been invested in preparing this part of the electronics. Apart from the FASTBUS electronics, this will require only cables and splitters. In addition to monitoring PMTs for signs of gain shifts or degradation, other information is available because of the fact that this part of the electronics will capture data event-by-event. This makes it useful for monitoring many properties of the detectors such as efficiency and time resolution as a function of position within the detectors, alignment of backup detectors with focal plane detectors, coincidences between focal plane elements, etc. Additionally this will sample the time spectrum (with a relatively simple dead-time correction), allowing the front-end electronics to be cross-checked, calibrated, and accurately corrected for dead-time effects. Acquisition of the commercial electronics is expected to be spread across FY 2000 and FY 2001 apart from individual units to be used for testing and to ensure suitability for the intended purpose.

There are several parallel efforts in development of forward-angle electronics. The North American and French groups will each produce electronics to read out their half of the detectors. In addition to providing a backup plan, should either design encounter unforeseen obstacles, this dual approach will allow some cross checking to ensure that neither design is undermined by unsuspected systematic errors. The French development project is further sub-divided into two parallel, but very distinct, efforts being carried out at IPN-Orsay and ISN-Grenoble. Both of the French designs will be prototyped, but it is intended that only one will be selected for production. All three designs have the same basic function, accumulation of time spectra for individual focal plane detector meantimes, in coincidence with a hit on the corresponding backup detector. These role of these detectors is distinct from the FASTBUS TDCs in two important ways. First, the forward-angle electronics must accept almost all of the coincidences, at a mean rate of over 1 MHz and an instantaneous rates of over 10 MHz (as opposed to the FASTBUS electronics which samples only a tiny fraction of the hits). Secondly, in order to achieve this very high encoding rate, only mean-time spectra are accumulated. No information is stored concerning correlations or different detectors, nor of time-differences between the PMTs of a single detector.

The North American and ISN-Grenoble designs are both based upon the same concept. High-speed shift registers, shifted by a clock-train synched to the beam burst are used to encode the arrival time of the hit as the depth to which the data shifts before the end of the clock-train. The parallel outputs of the shift resistors are then strobed into scaler channels, incrementing the time spectra stored there, before the shift registers are reset for the next

beam burst, 32 ns later. The differences lie mainly in the implementation, with the North American design being more modular and the ISN-Grenoble design more integrated. In the North American design the meantimers and scalers are in separate units connected by ribbon cables to the time-encoding board. ISN-Grenoble is developing custom ASICs, one to perform the meantiming, another to perform high-speed scaling, and possibly a third to serve the shift-register function. Their single board will serve the functions of meantiming, determining coincidences, time-encoding, scaling, and VME interface. Only constant fraction discriminators (CFDs), and splitters are required as separate modules. The North American design, on the other hand performs only the coincidence-detection and time encoding on the custom board (in addition to support services, such as dead-time monitoring) and employs separate modules for CFDs, meantimers, and VME-scalers. Assuming the ISN-Grenoble ASIC-development project is successful, the North American design may benefit from low-cost scaler and meantimer modules in place of the originally-planned commercial units.

The IPN-Orsay design differs substantially from that described above. It even more integrated than the ISN-Grenoble design, in that it includes the CFDs on the single board being developed. More significantly, the heart of the time encoding is a completely different, using flash TDCs passing data (through FIFO buffers) to a set of DSPs which assemble the spectra in memory to be read out between macropulses by an additional DSP which passes the data to VME-accessible memory. The time resolution of the flash TDCs is 250 ps, compared to the 1 ns resolution of the shift register technique.

The North American time-encoding board has been prototyped (along with the support board needed to produce clock trains) and tested. Additional features have been added to aid in monitoring deadtime, to simplify external cabling, and to detect errors caused by noise or bad cables. A first "production" board has recently been printed and stuffed and is now undergoing testing. Assuming only minor modifications are required, full scale production of these boards can begin in early 1999, subject to funding. Acquisition of commercial scalers and meantimers will be delayed until at least FY2000, allowing the possibility that a more economical solution can be found, using boards incorporating the ISN-Grenoble ASICs.

ISN-Grenoble is pursuing two ASIC designs for the meantimer. The first has already been prototyped and has been found to perform well when provided with suitable temperature feedback. The second design is presently being prototyped, and is expected to be more intrinsically stable. The prototype ASIC for the 32 channel 100 MHz scaler has also been delivered, and will be tested in the near future. Testing will include production of a VME board which may eventually be used as the external scaler module for the North American design. This VME board is expected to be tested and ready for use in January of 1999. The time-encoding board incorporating the meantimer and scaler ASICs and the time-encoding shift registers is expected to be ready for testing by February of 1999. This may draw upon the experience from tests of the North American board.

The IPN-Orsay board is being laid out, and the first prototype is expected by January of 1999. The components of this board are existing ICs, but some programming and testing will be needed. It is expected to be ready for testing in March of 1999.

Comparisons of the two French designs are expected to be carried out, using realistic scintillator signals, in March of 1999. By the end of April, a decision will be made on which of the two solutions to use to instrument the four octants being instrumented by the French. Whichever solution is selected will then go into production, and is expected to be ready for delivery by February of 2000.

Three solutions are also being pursued for the back-angle electronics. The time-frame for their development is less critical since they will not be used for early running of G^0. The demands on the back-angle electronics are also less strong, since time-encoding will not be required. Production of the North American back-angle electronics is expected to begin in early FY 2000 and to be completed in November of 2000. The two French designs for the back-angle electronics are modifications of the forward-angle designs, and will be pursued in parallel. Whichever design is selected is expected to be completed along with the corresponding forward-angle electronics by February of 2000.

5.6 Infrastructure

JLab is providing material, equipment, and services to G^0 as a part of the infrastructure of Hall C. In addition, some modifications will be required to existing equipment in the hall.

5.6.1 G^0 Installation & Shielding

The planning, material, services, and labor required to install the collaboration deliverables (SMS, target, detectors, etc.) and to establish an interface to the Hall C infrastructure is covered by this task. The physical location of the G^0 experiment will be down stream of the Hall C spectrometer pivot assembly. This has the advantages of making G^0 minimally invasive to the other Hall C experimental programs and allowing the simplest G^0 staging arrangement. Based on preliminary radiation calculations it is also the best siting for minimizing overall beam produced backgrounds in Hall C.

5.6.2 Hall C Electrical

Infrastructure services and equipment related to the electrical systems of G^0 includes: 1) signal and control cables connecting the experiment to counting room patch panels (their fabrication and installation and mechanical support), additional patch panels for intermediate break-out; 2) AC power in Hall C for vacuum, cryogenic systems instrumentation, target instrumentation, gain monitoring system instrumentation etc.; 3) high voltage supplies installed In Hall C along with cables, cable mechanical support and high voltage patch panels (If needed), and 4) the construction of a G^0 electronics and counting room with its required infrastructure including AC power, air conditioning, racks, and modular electronics crates.

To date all signal cables have been purchased and delivered at a cost significantly below the budget estimate.

5.6.3 Beamline Elements

Careful measurement of the parameters of the electron beam will be necessary in order to control systematic uncertainty in the G^0 measurement. This will require beam monitors including: 1) RF cavity position/Intensity monitors, and other beam position monitors (stripline, harp wire scanners). Also included in this item are electronics systems associated with the electron beam such as the raster system and the helicity readout from the polarized source in the counting room. Also included in this task is the work and material needed for the modification and adaptation of the Hall C Moller polarimeter to the needs of the G^0 experiment. Finally, mechanical modifications to the beam line such as well as the vacuum system for the SMS and valves to permit the isolation the SMS are included here.

An instrumentation girder is under design which will contain the rf cavities, stripline monitors and a harp wire scanner. This self contained girder package is very similar to the new girder package currently being completed for the upcoming Hall C program. The G^0 girder package will be located in upstream of the G^0 target system which is itself upstream from the magnet/detector assembly. This self contained instrumentation girder will be removed and stored between G^0 runs. By locating G^0 downstream of the pivot and employing a dedicated beam monitoring instrumentation package G^0 will have the advantage of obtaining access to signals from three separate beam monitoring packages. Specifically, the one in the tunnel to Hall C, the package in front of the standard Hall C scattering chamber and the G^0 package. This should result in excellent monitoring of all beam properties.

5.6.4 Cryogenic Services

The G^0 SMS, the target, and the Moller polarimeter will require cryogens from the end Station Refrigerator. To accommodate G^0 the cryodistribution system must be upgraded to provide cryogens to the target and the SM. Flexible "U-Tubes" for delivery of cryogens to the SM and the target will be fabricated.

Since G^0 is now located downstream of the standard Hall C pivot a satellite cryogenic "well head" will be installed near the planned G^0 location. Since this satellite "well head" will likely be used for future Hall C experiments (beyond G^0) the funds for this work are coming from the Hall C general operations budget and a not part of the scope of the G^0 experiment. Engineering design work for the G^0 specific (and funded) transfer lines is also under way.

5.6.5 Engineering and Design

This task covers the engineering and drafting effort associated with the mechanical supports, cryogenic plumbing, shielding, and other additions and modifications to the Hall C environment that are specifically required by the G^0 experiment, i.e. engineering and drafting for the other Hall C Infrastructure tasks.

5.6.6 Support Structures

This task includes all labor and material required for the fabrication, and assembly of the mechanical support of the G^0 detectors. The support consists of individual CED and FPD octant support frames, associated with the North American and the French detectors, which "plug in" to a detector superstructure (the so-called Ferris wheel). The alignment of CED and FPD octant modules is accomplished with adjustment degrees of freedom provided by the Ferris wheel. Internal alignment of scintillator elements within octant supports is established when the octant modules are assembled. Lead and borated polyethylene shielding an well beam line material Integral to the Ferris wheel support will be fabricated as part of this task. A rail system will permit the Ferris wheel to be retracted from the SMS for, servicing. The support frame (Detector Assembly Support Frame) to hold both the North America and French detector modules is under final design. The drawing package should be ready for bidding around March 1999.

Since the original G^0 concept was for the stationary placement of the experiment and the selection of the downstream placement option requires that is be easily moved out of the beamline so other experiments can run in Hall C a rail motion system is under development. This rail system is for moving the G^0 magnet and DASF out of the beam line and the separation of the Magnet and DASF in order to allow the SOS to reach its full angular range. Time to complete a drawing package for the rail system is 2-3 months. Since this is a requirement for other experiments to run easily in Hall C the costs of designing, building and installing this rail system will be absorbed by the general hall operations budget and consequently is not part of G^0's scope.

5.7 Computation

The software effort associated with the G^0 experiment has been divided into four parts: slow controls, data acquisition software, analysis, and simulations. Separate teams will focus on the creation of software to meet the requirements of the experiment in these areas.

5.7.1 Slow Controls

The slow controls group is charged with the integration of slow controls hardware and software, provided as part of other subsystem deliverables, into a unified system. This will involve communication with stand-alone systems associated with the spectrometer magnet/cooling control system the target and the accelerator. Mechanisms for dealing with these slow controls front-end systems programmed with Lab-view and EPICS will be provided. In addition, specialized software for communication with beam diagnostic systems (such as current, beam position, and helicity monitoring) as well as electronics which requires external parameter down-loads will be written. User-friendly displays will be provided to indicate status and alarm conditions.

Leadership for the slow controls effort will come from the NMSU group. The design of the slow controls system is still at the planning stage. Completion of a design report awaits

the definition of the control systems for the target and magnet. The initial version of slow control software will be provided for testing at UIUC late in 1999. Subsequent versions will then be tested and finally used during the experiment commissioning at JLab.

5.7.2 Data Acquisition

The creation of CODA software necessary for reading out the electronics to produce a data stream, for storing that data stream, for backing up that storage to tape and for providing hooks for on-line analysis of the data stream are all within the scope of the G^0 data acquisition effort In addition an interface to the slow controls software must be maintained to allow slow controls parameters to be inserted into and stored along with the data stream.

The current effort is to produce a final definition of the hardware to be read out by the DAQ software. This is expected later this spring following the decision on the electronics for the French octants. The first version of the code will be developed to provide a test stand for detector octants as they are assembled.

5.7.3 Analysis

Another area of computation involves extraction of physics and diagnostic results from the data stream produced by the experiment. The analysis effort is dominated by the calculation of asymmetries and the determination of systematic uncertainties. An on-line code must be prepared in time for the commissioning experiment. To achieve this goal, the software will be tested ahead of time with pseudodata produced by simulation codes. As the experiment matures, it is expected that the on-line analysis code will evolve to become the production off-line code. The bulk of the off-line analysis will be carried out by thesis students. The analysis effort will therefore involve coordination of parallel analysis tracks and documentation of the analysis for eventual publication.

5.7.4 Simulation

The development and maintenance of standard simulation codes and their application to predict the behavior of the apparatus and to contribute to its design, is another vital computational task. There are currently six areas of study for the simulation of the G^0 experiment.

1. G^0 GEANT, a GEANT 3.2.1 based Monte Carlo will initially focus on the determination of background rates, signal rates, and the design of shielding. It will eventually be used to model kinematic acceptance. The current version of the program includes an updated geometry definition and re-written procedures for extracted energy deposition in the detectors. Future releases will incorporate a more exact representation of the spectrometer field, and a faster tracking algorithm in the region of vacuum and magnetic field.
2. Precision trajectory calculation codes including the Tracktor family of programs developed by Ron Laszewski (UIUC), a similar code written by Fernand Merchez (IPN-

Orsay), and a TOSCA model of the spectrometer are employed to accurately and quickly track particles through the magnetic field for optics studies and detector design.

3. Light guide simulation programs GUIDEM and GUIDEIT-SW, based on CERN program Guide-7 are being used to simulate light propagation in the detectors.
4. P. Degtiarenko of the Jefferson Lab RadCon group will provide information on detector dose rates.
5. Electronics simulation codes are being used for the study of pile-up and dead-time corrections.
6. A code, still in the conceptual stage, perhaps employing results of 1-5 above, will be developed to permit the simulation of effects contributing to our systematic uncertainty and false asymmetries.

The simulation task includes the maintenance of standard versions of the above codes. This will include documenting them to a level which would allow the average graduate student to use them with only minimal consulting with the authors. The task also involves running the codes to answer a list of questions/issues provided by the Experiment Coordinator.

6 Beam Time Request

In the December 1993 proposal we requested a total of 164 d (3940 h) of beam time to complete measurements of forward and backward asymmetries in the range $0.1 \leq Q^2 \leq 0.5$ GeV^2. Of this time, the 46 d (1100 h) for commissioning was approved. *At this time we request that 46 d of commissioning time again be approved.* We plan to return to the PAC for approval of the first physics measurement in the near future.

The commissioning plan envisioned in 1993 is essentially unchanged. We anticipate breaking the time into two runs of approximately 3 weeks or about 6 calendar weeks each (running with the fully instrumented spectrometer and the liquid hydrogen target). The details of the measurements for the two runs are as follows:

1. Run 1
   - check spectrometer optics (shape of constant Q^2 locus at focal surface, etc.): 3 days
   - backgrounds: external shielding, set field to low value to investigate neutrons and γ's: 4 d
   - detector efficiencies, ADC and TDC spectra, overall device symmetry: 2 d
   - begin to establish procedure for centering beam with respect to target and detector: 2 d
   - studies of beam polarization (current dependence of polarization): 1 d
   - begin measurement of correlated parameter derivatives (yield with respect to beam position, etc.): 2 d
   - first asymmetries: 5 d
   - empty target (background, symmetry, etc.): 2 d
2. Run 2
   - more background studies: 4 d
   - final procedure for centering: 3d
   - final correlated parameter derivative study: 4 d
   - asymmetry test: 10 d

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