The G^0 Experiment At Jefferson Lab

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Abstract. The electron-proton parity-violation G^0 experiment at Jefferson Lab aims to make a determination of the ‘strange’ quark currents in the proton. Two *new* proton ground state matrix elements will be measured which are sensitive to point-like ‘strange’ quarks and hence to the quark-antiquark sea in the proton. The matrix elements of interest are the elastic-scattering vector weak neutral-current ‘charge’ and ‘magnetic’ form factors, G_E^Z and G_M^Z , respectively. By measuring the very small parity-violating asymmetries in elastic electron-proton scattering at momentum transfers between 0.1 and 1.0 GeV^2 , and combining these asymmetries with previously measured electromagnetic form factors, *new* information about the proton weak form factors can be obtained. This new high precision experiment is presently in the installation and commissioning phase.

INTRODUCTION

The detailed structure of the nucleon at low energies is not well understood within the framework of quark and gluon degrees of freedom. For example, relatively little is known about the importance of the quark-antiquark sea at these energies. However, since strange quarks contribute only to the sea, direct information about the role of the quark-antiquark sea can be gleaned through determinations of the strangeness content of the nucleon. In particular, the strange quark contributions to the ‘electric’ and ‘magnetic’ properties of the nucleon can be determined through measurements of the nucleon weak vector form factors [1,2].

Parity-violating (PV) electron-nucleon elastic scattering offers a unique opportunity to study the electroweak structure of the nucleon [1]. The electroweak interaction takes place at first order through two processes, involving the exchange of a virtual photon (γ) and the exchange of a Z^0 , respectively, with 4-momentum transferred $-Q^2$. Parity violation arises through the interference of the γ and the Z^0 exchange amplitudes and can be characterized by the ratio of the helicity dependent to helicity independent cross sections, or the PV asymmetry:

$$A = \left[\frac{1}{P} \right] \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} \quad (1)$$

where σ_R and σ_L are the cross sections for right- and left-handed electrons, respectively. For elastic electron-proton scattering, the PV asymmetry can be expressed as:

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$$A = \left[\frac{-G_F Q^2}{4\sqrt{2}\pi\alpha} \right] \frac{\varepsilon G_E^\gamma G_E^Z + \tau G_M^\gamma G_M^Z - (1 - 4\sin^2 \theta_W) \varepsilon' G_M^\gamma G_A^e}{\varepsilon (G_E^\gamma)^2 + \tau (G_M^\gamma)^2} \quad (2)$$

where G_E^γ and G_M^γ are the usual proton electromagnetic form factors, G_E^Z and G_M^Z are the proton weak vector form factors, and G_A^e is the axial form factor of the proton. At a given Q^2 , measurement of the PV asymmetry at forward and backward angles allow for the determination of the proton weak vector form factors via a Rosenbluth type separation. When combined with knowledge of the usual proton and neutron electromagnetic form factors, the strange quark contributions (G_E^S and G_M^S) to the nucleon's structure can be extracted. This extraction relies only on the SU(3) and charge symmetry of the nucleon.

THE G^0 EXPERIMENT

In pursuit of some of the goals described above, a number of dedicated PV asymmetry experiments [3,4,5] have been proposed, developed and several have been completed over the last decade. These experiments have either measured a linear combination of form factors (e.g. $G_E^S + 0.39G_M^S$) [4] or have utilized kinematical suppression to isolate one of the form factors (G_M^S) [5]. In contrast, the G^0 experiment [6] proposes to perform the full separation of the strange electric G_E^S , magnetic G_M^S and axial G_A^e form factors and to characterize the Q^2 evolution of these observables by carrying out the measurements at three different momentum transfers 0.3, 0.5 and 0.8 (GeV/c)². To accomplish this, a first set of asymmetry measurements will be performed at forward electron scattering angles between 7° to 15°, accessing a range of Q^2 between 0.1 and 1.0 (GeV/c)². This first measurement is carried out at a single electron beam energy and makes use of a hydrogen target. Following this, a second set of asymmetry measurements will be performed at backward electron scattering angles centered at 110° and will require measurements on both hydrogen and deuterium targets. Due to the limited Q^2 acceptance at these backward angles, three separate measurements are planned at incident electron beam energies of 424, 525 and 799 MeV, which correspond to $Q^2 = 0.3, 0.5$ and 0.8 (GeV/c)², respectively. Figure 1

FIGURE 1. The projected errors for the G^0 measurement compared with two different models.

shows the projected total errors for the G^0 measurements along with two theoretical predictions, one based on a Chiral Perturbation Theory calculation [7] and the other based on a Lattice QCD calculation [8]. The projected errors in figure 1 include contributions from statistical uncertainties ($\Delta A/A = 5\%$), uncertainties from systematic effects, as well as uncertainties associated with the ‘known’ values of the proton and neutron electromagnetic form factors. The overall uncertainties are dominated by the statistical errors.

An important consideration for these types of parity-violation measurements is false asymmetries associated with helicity-correlated modulations in the beam properties. The G^0 requirements for the beam properties are summarized in Table 1.

TABLE 1. Beam Requirements for G^0

Beam parameter	Nominal value	Helic. Corr. Asym (in 30 days)
Current	40 μA	< 1 ppm
Energy	3 GeV	< 2.5×10^{-8}
Position	-	< 20 nm
Angle	-	< 2 nrad

The G^0 Apparatus

The G^0 measurement will be carried out at Jefferson Lab, in the Hall C experimental area. The experiment will require a source capable of delivering a 40 μA electron beam with 70% polarization to a 20 cm long cryogenic target. A specially designed superconducting toroidal spectrometer, with azimuthally symmetric angular acceptance has been constructed. In the forward angle mode (shown in figure 2), individually scattered particles will be detected and counted by a set of 16 scintillator pairs, located at the focal surface of each spectrometer octant. The bend angle through the magnet is $\sim 35^\circ$ and eight sets of collimators (not shown in figure 2) located in the magnet gaps shield the detectors from a direct view of the beam. Shown in figure 3 are: one octant of scintillator pairs; and eight complete sets of scintillator arrays, mounted within eight light-tight modules, and installed on the detector support structure.

FIGURE 2. Schematic layout of the G^0 spectrometer and the forward angle mode of the experiment.

FIGURE 3. One set of Focal Plane scintillators and all eight sets loaded onto the main Detector support structure.

In this first phase of the experiment, the beam energy is fixed at 3 GeV and recoil protons from the e-p scattering process are detected at $\theta_p = 70^\circ \pm 10^\circ$ (or $\theta_e = 11^\circ \pm 4^\circ$). Time-of-flight measurements over a 32 ns time-window will be used to supplement momentum selection by the spectrometer and to discriminate between elastic and inelastic scattering processes. Custom time-encoding electronics allow readout at high detector rates, of the order of 2 MHz per scintillator pair. To enable proper operation of the time-encoding electronics, the electron beam will be pulsed at 31.25 MHz (the 16th subharmonic of the usual 499 MHz pulse structure).

In the second phase of the experiment, the detector and spectrometer system will be rotated back-to-front to detect the back-scattered electrons at $\theta_e = 110^\circ \pm 10^\circ$, allowing a reasonable lever arm for a Rosenbluth separation. For this backward angle configuration, each incident beam energy will correspond to a different Q^2 measurement, and time-of-flight techniques will not adequately discriminate between elastic and inelastic scattering processes. Instead, an additional array of scintillation detectors located near the spectrometer cryostat exit of each octant, will enable kinematic separation of the elastic and inelastic electrons.

Results from the SAMPLE experiment [5] at the MIT-Bates laboratory have shown the importance of measuring the axial form factor complete with radiative corrections. In order to perform the separation of the proton axial form factor from the weak vector form factors, further asymmetry measurements must be carried out using a deuterium target. However, for the deuterium measurements, pion backgrounds are a significant issue and special low-index aerogel Cerenkov counters will be required to provide π/e separation. The schematic layout of the G^0 backward angle configuration is shown in figure 4.

SUMMARY

The G^0 experiment proposes to measure and fully separate the strange electric (G_E^S), magnetic (G_M^S), and axial (G_A^e) form factors of the nucleon and to characterize the Q^2 evolution of these observables by carrying out the measurements at different

FIGURE 4. Schematic layout of the G^0 backward angle configuration.

momentum transfers. Determinations of these observables may shed light on the role, at low energies, of strange quarks and the quark-antiquark sea in the nucleon. As well, G_A^e may provide valuable information on the proton anapole moment. Presently, this experiment is in the installation and commissioning phase at Jefferson Lab in Hall C. All subsystems for the first phase, forward angle measurements have been installed. Commissioning of the G^0 apparatus will take place between October 2002 to January 2003, followed by the actual 'physics' run some time later (possibly in late 2003). Upon completion of the forward angle measurements, the 'turn-around' of the G^0 apparatus will be carried out, and data-taking for the backward angle program could start in 2005.

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