The Strange Form Factors of the Proton and the G^0 Experiment

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The measurement of parity violating asymmetries in elastic electron-nucleon scattering can be used to determine the contribution of strange quark-antiquark pairs to the form factors. It is the aim of the G^0 experiment at Jefferson Lab to perform the complete separation of the electric and magnetic strange form factors over a broad range of Q^2. The G^0 forward-angle measurements were completed in 2004 and preliminary results will be presented. The first G^0 backward-angle measurements will take place in late 2005. Preparations for those measurements are under way and will be discussed.

1. Parity-Violating Elastic Electron Scattering from Nucleons

Parity-violating (PV) asymmetries are dominantly sensitive to the interference of single-photon exchange and single-Z^0 exchange graphs. Experiments measure the scattering asymmetry with an unpolarized target under the reversal of electron helicity [1–3]:

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

where R and L indicate the electron helicity, G_F is the Fermi constant, α is the fine structure constant, θ_W is the weak mixing angle, and Q^2 is the negative four-momentum transfer squared. The factors ϵ, τ, and ϵ' are kinematical factors, and G_E and G_M are the electromagnetic form factors of the proton determined from parity-conserving elastic scattering. The functions G_E^Z, G_M^Z, and G_A^e are new form factors related to the exchange of the Z^0. The contributions of electroweak radiative corrections are important to make an accurate extraction, but have been omitted for clarity.

The electromagnetic form factors G_E and G_M and neutral weak form factors G_E^Z and G_M^Z can be decomposed into contributions from u, d, and s quarks. A determination of the neutral weak form factors then allows a determination of the strange form factors G_E^s and G_M^s via:

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

where the proton p and neutron n electromagnetic form factors are denoted.

By performing PV asymmetry measurements at forward angles from the proton, and at backward angles from the proton and deuteron, G_E^s, G_M^s, and G_A^e can be extracted. Previous experiments [4–6] have begun this work. Preliminary results from recent experiments and plans for future experiments were discussed at this conference [7,8]. It is the aim of the G^0 experiment to make the complete separation at three different Q^2 values of 0.3, 0.5, and 0.8 $(\mathrm{GeV/c})^2$. The experiment is being conducted in Hall C at Jefferson Lab in Newport News, Virginia, USA.

2. G^0 Forward-Angle Experiment

2.1. Description of the Experiment

The electron beam was generated by the CEBAF polarized injector using a dedicated laser beam striking a strained GaAs crystal. This gave beam polarizations of typically 75%. The beam was accelerated by the CEBAF accelerator and delivered to Hall C at a current of 40 μA and an energy of 3.03 GeV. The beam was pulsed at a rate of 31 MHz in order to make use of a time-of-flight technique for particle identification. Beam charge and position monitors in the hall were used to determine helicity-correlated current and position information and to periodically alter injector parameters to minimize helicity-correlated beam effects. A half-wave plate, which reversed the laser and hence the electon helicity was periodically inserted as a systematic check of this procedure.

The electron beam impinged upon a 20 cm liquid hydrogen target. The hydrogen was circulated at high rate in order to prevent target boiling. Elastically scattered protons passed through a superconducting toroidal spectrometer which focused the protons and sorted them in Q^2. Sixteen pairs of scintillation counters, shaped to the focal plane and acceptance of the spectrometer, detected the elastically scattered protons. The detectors were numbered from one to sixteen where detector one was closest to the beam pipe and sixteen farthest away. Lower numbered detectors therefore indicate lower Q^2 and higher number detectors indicate higher Q^2 where the total range of Q^2 is from 0.1 to 1.0 $(\mathrm{GeV/c})^2$. Each ring of detectors was divided into eight octants, employing a high degree of azimuthal symmetry about the beam axis to minimize the sensitivity to helicity-correlated beam motion.

Particle identification was performed by time-of-flight (TOF) where the start was indicated by the arrival of a beam pulse at the target (signalled by a cavity monitor upstream) and and the stop was indicated by a coincidence between a given pair of scintillators. Recoiling elastic protons would in general have the slowest arrival time, for a given pair of scintillators. Positively charged pions would have the fastest arrival time. Inelastic protons from e.g. the Δ resonance would have an intermediate arrival time. This resulted in a TOF spectrum with three peaks.

The typical coincidence rate was of order 1 MHz in each detector pair. To measure TOF spectra at such a high rate required the use of a combination of custom and commercial electronics.

2.2. Systematic Effects and Uncertainties

Asymmetry data were corrected for residual helicity-correlated beam properties using measured detector sensitivities. Deadtime corrections were also performed on the raw detector rates. The asymmetries were then corrected for backgrounds. Beam polarization corrections and electromagnetic radiative corrections must then be applied in order to arrive at the physics asymmetry.

Systematic uncertainties due to helicity-correlated beam properties were small, of order 0.01%, owing to the careful feedback and control procedure described above. Deadtime corrections could be performed reliably at the <2% level.

Leakage from the other Halls' beams at the usual CEBAF 499 MHz into the 31 MHz G^0 beam was found to present a background to the experiment. Though this so-called leakage beam represented only 0.1% of the total beam current, the helicity properties of this beam were poorly controlled and presented typically a several hundred ppm asymmetry. Fortunately, regions of the TOF spectrum which were populated by elastic scattering from the leakage beam could be used to determine its contribution on a run-by-run basis. A correction procedure employing these regions of TOF was validated in dedicated runs turning off and on the various lasers at the injector, resulting in a systematic uncertainty of 0.1 ppm due to leakage beam.

The dominant systematic effect arose due to physics backgrounds owing to imperfect separation of the so-called inelastic peak from the elastic peak in the TOF spectrum. Extrapolation techniques show that this background ranges from about 8% in the lower detectors to 16% in the higher detectors. These techniques are well-motivated by Monte Carlo simulations. Additionally the asymmetry of the protons in the inelastic peak can be large, of order tens of ppm, and can vary across the elastic peak. This is seen by considering the asymmetry in the side bands of the elastic peak. This makes the systematic uncertainty due to the background asymmetry underneath the peak difficult to estimate based on extrapolation techniques alone. For the preliminary result, a linear interpolation of the background asymmetry was used. However, for the final result, a more refined technique involving simultaneous fitting of both the yield and asymmetry as a function of TOF will be used. Additionally, recent Monte Carlo calculations involving hyperons show an asymmetry similar to that observed in the higher-numbered detectors. The asymmetry originates in the self-analyzing weak decay of Λ and Σ hyperons, where decay protons scatter from the spectrometer collimators and are subsequently detected. This work will allow us to more confidently estimate the systematic uncertainty associated with the background correction.

The normalization uncertainty due to beam polarization is 2%. The systematic uncertainty due to Q^2 determination was found to be 1%, through a technique involving varying the magnetic field of the spectrometer and comparing rates to simulations. Determination of electromagnetic radiative corrections is underway and the correction is expected to be small.

2.3. Preliminary Result

The preliminary result for the experiment is displayed in Fig. 1. This represents the full statistics of the experiment. Not all detectors are displayed, owing to the larger systematic uncertainties due to backgrounds in the larger detectors, which are still being analyzed. A 25% global blinding factor is applied to the data in order to prevent interpretation in terms of form factors until analysis of all corrections is complete. The figure therefore presents the overall quality of the data and the current status of the analysis.

3. G^0 Backward-Angle Experiment

In backward-angle mode, the magnet and detectors will be rearranged so that the detectors are upstream of the magnet and so that elastically scattered electrons are detected. As elastic and inelastic electrons are not separable by the TOF technique, additional detectors must be inserted to define the trajectories of the electrons and to perform par-

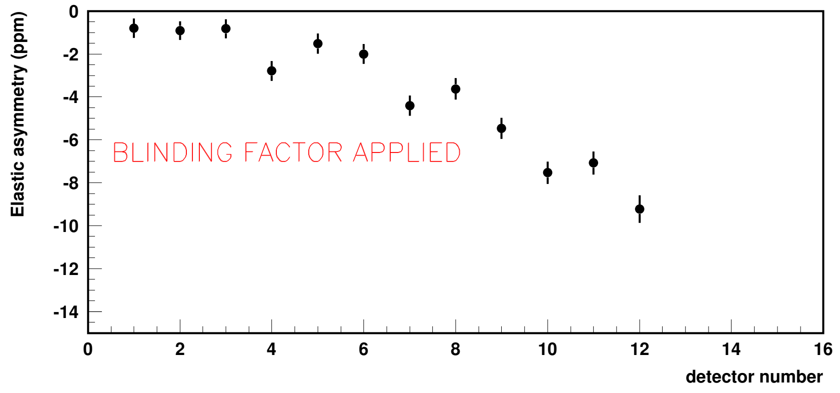

Figure 1. G^0 forward angle preliminary result. Elastic asymmetry as a function of detector number is displayed. Lower detectors indicate lower Q^2 and higher detectors indicate higher Q^2.

ticle identification. These modifications involve a new plane of scintillators (cryostat exit detectors or CED's) and an aerogel Čerenkov counter, for each octant. Since TOF will not be useful, the experiment would run at the usual CEBAF frequency of 499 MHz at a current of 80 μA. New trigger and coincidence-finding electronics are therefore required to perform the experiment. The experiment would run at three different beam energies to obtain three different Q^2 values each on hydrogen and deuterium targets. The first backward-angle run will use a beam energy of 0.799 GeV, corresponding to a Q^2 of 0.8 $(\mathrm{GeV/c})^2$, and will occur in late 2005.

4. Summary

PV elastic scattering of electrons from nucleon targets gives information on the contribution of strange quarks to the nucleon form factors. The G^0 experiment aims to make the separation of the electric and magnetic pieces over the broadest range of Q^2 ever accessed. The G^0 forward-angle measurements have been completed and analysis of the data is nearing completion. Preparations for the backward-angle experiments are underway and the first set of runs will occur in late 2005.

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