Good afternoon. I would like to talk today about the measurement of the charge of factor of the neutron done at the Jefferson Lab last year. Here is the outline of my talk: I'm going to start with the background and motivation behind this experiment, then I will briefly describe the formalism of double polarization G_E^n experiments, then I will describe the experimental setup, then I will give an outline of our data analysis and I will conclude by presenting our preliminary results.

Motivation. G_E^n is a quantitative estimate of the charge distribution in the neutron and thus is important for our understanding nuclear structure. It also provides a means of testing various models of nucleon structure and gives rise to a non-negligible contribution in electromagnetic electro-nuclear scattering. Despite a great effort focused on its determination , the electric form factor of the neutron, G_E^n , remains poorly known. Two major difficulties faced by experimenters in their studies of G_E^n are its small magnitude and lack of a free neutron target. Unpolarized cross-section measurements, used for determining G_E^n up to 90's, were incapable of overcoming these difficulties and yielded inconsistent or model-dependent results.

Recent technological advances in high duty factor accelerators, polarized sources, polarized targets and recoil polarimetry made possible double polarization methods of determining G_E^n , which use asymmetry rather than cross-sections and thus reduce model-dependence and improve achievable accuracy.

In our experiment we scattered a longitudinally polarized electron beam off a polarized deuterated ammonia target. The polarized electron-nucleon scattering cross section consists of a helicity independent part Σ and a part that flips the sign whenever the helicity is inversed. The helicity induced asymmetry, given by the ratio of these two parts, depends on the G_E^n . For a general orientation of the target polarization this dependence is complex. In order to minimize the influence of the magnetic form factor G_M^n and maximize the sensitivity to G_E^n the direction of the target polarization was chosen to be perpendicular to the three momentum transfer $\vec{q}$ and to lie in the scattering plane. For this case the expression for the electron-neutron asymmetry A_n simplifies to the following:

$$A_n = \frac{-2\sqrt{\tau(1+\tau)}G_M^n G_E^n}{(G_E^n)^2 + \tau(1+2(1+\tau)\tan^2(\theta/2))(G_M^n)^2}; \tau = \frac{Q^2}{4M^2}$$

,
where θ_e is the electron scattering angle and M is the neutron mass.

Realistically, in electron-deuteron scattering experimetns we are dealing with electron-deuteron asymmetry A_{ed}^V rather than an electron-neutron asymmetry,and hence one needs to take into account final state interactions and subnucleonic degrees of freedom (meson exchange currents, isobar configurations). In the quasi-elastic region with a neutron emitted in the direction of the three momentum transfer $\vec{q}$ these corrections are minimal while sensitivity to G_E^n was maximal. Nevertheless, these corrections were taken into account using calculations done by H. Arenhövel.

1 Experimental setup

In E-93026 measurements were taken at two points, $Q^2 = 0.5$ and $Q^2 = 1.0$. Results are presented here only for $Q^2 = 0.5$.

The polarized electron beam was provided by the Jefferson Lab accelerator, operating with 100% duty factor and capable of delivering polarized electron beam to three experimental halls at the same time. For $Q^2 = 0.5$ the beam energy was 2.332 GeV with the average polarization of about 75%. The beam polarization was measured using a high precision Moeller polarimeter which allowed to achieve an accuracy of 1% in about 20 minutes of measurement time. The maximum value of the beam current in the accelerator can reach 100 μA, however, it was limited to 100 nA because of radiation damage to the target. For the same reason a system of raster magnets was used to distribute the beam heat and radiation damage to the target uniformly over the face of target. The readings of the raster magnets were also used by the reconstruction algorithm to determine the horizontal and vertical position of the interaction of the electron with the target nucleus.

The solid polarized target was developed by University of Virginia and was successfully tested in two experiments prior to being used in E-93026. The basic components of the polarized target include a superconducting magnet operated at 5 Tesla, a ^4He evaporation refrigerator, a pumping system, a high power microwave tube operating at frequencies around 140 GHz and an NMR system for measuring the target polarization. The target material was polarized using the principle of dynamic nuclear polarization (DNP). The DNP technique requires the target materials to be doped (in our case this was achieved by irradiation). By applying the microwave power the high electron polarization (due to large electron magnetic moment) was transferred to the nuclei. The target polarization was determined by measuring the impendance change of the series resontant LCR circuit caused by a change in magnetic susceptibility of the nuclear spin system due to the nuclear magnetic dipole moment. The conversion constants between the area of the NMR signal and the target polarizion were obtained by a series of thermal equilibrium (TE) measurements. The target polarization typically varied between 15% and 35% and averged to 22%.

As we have noted earlier, the polarized target needed a high 5 Tesla magnetic field for its normal operation. This field lead to deflection of electrons and protons. In order to insure the normal incidence angle of the incoming beam and the bend the beam after target so it would arrive to the beam dump, a series of chicane magnets was used.

After interaction with a polarized deuteron in the target material, the scattered elecrons were detected in the High Momentum Spectrometer of Hall C in coincidence with knocked-out nucleons. The HMS is the standard piece of equipment of Hall C. It consists of a collimator system, three quadrupoles, one dipole, and a package of detectors in the detector hut: two drift chambers, two hodoscopes and gas Čerenkov counter and a lead-glass shower counter. The HMS is capable of detecting electrons with energies up to 7.5 GeV. The solid angle acceptance of HMS is $d\Omega$ ~6mSrad and the momentum acceptance is about 20% of the central momentum. The resolution of the HMS is: $\delta p = 0.1\%$ and $\delta\theta(\phi) \sim 1$mrad. During $Q^2 = 0.5$ the HMS was set at 18.5° with respect to the direction of the incident beam.

The neutron detector was assembled from plastic scintillators. It consisted of two planes of thin paddles used for particle identification and 6 bar planes for neutron detection. In addition, it used two vertical sticks for vertical position calibration. The detector was set at 60.51° (along the direction of the three-momentum transfer) and was enclosed in a thick concreted walled hut open towards the target. The neutron vertical position was determined by the segmentation of the detector (10 cm) while the horizontal position was determined from the time difference of the phototubes.

During data-taking there was no coincidence trigger between HMS and the neutron detector, the coincidence requirements were imposed on an event during the off-line analysis. The electrons in the HMS were reconstructed using the standard HMS reconstruction code extended for the effects of beam raster and target magnetic field. On the neutron detector side a custom tracking algorithm was developed for proper particle identification. Neutrons were defined as events with no hits in the paddles along the track to the target, within a narrow time interval and within a 100 MeV interval around the nucleon mass. A number of other cuts was applied to optimize the dilution factor and limit the recoil momentum to values where FSI and MEC corrections are small.

After event reconstruction and event selection charge and dead-time normalized yields were produced for each beam helicity state, N^+ and N^-. From these yields the raw asymmetry ϵ was calculated:

$$\epsilon = \frac{N^+ - N^-}{N^+ + N^-} = P_B P_T f A^V_{ed}.$$

In order to relate the raw experimental asymmetry ϵ to the A^V_{ed} one needs the knowledge of the dilution factor f in addition to beam and target polarizations P_B and P_T. This quantity accounts for scattering from nuclei other than deuterium and was determined from Monte Carlo simulations. Further, a number of corrections needs to be applied to the experimental asymmetry before the G^n_E can be extracted, including accidental background, proton contamination and radiative effects.

In order to extract G^n_E , the corrected experimental asymmetry needs to be compared to the theoretical asymmetry averaged over the experimental acceptance. The theoretical asymmetries were calculated on a grid of four kinematic variables under 3 different asummptions of the magnitude of G^n_E . Asymmetry values between grid points were obtained by interpolation. Averaged theoretical asymmetry was then fitted to the experimental values binned in the kinematic variables resulting in four numbers (thus providing an additional consistensy check).

The first pass analysis of the $Q^2 = 0.5$ data yielded the value of 0.87 for G^n_E in units of Galster parametrization. The statistical error of 7.4% should be combined with the systematic error of $6-8\%$ to obtain the total error bar. The leading contribution to the systematic error is due to the target polarization and model-dependence of the dilution factor.