Measurement of the Electric Form Factor of the Neutron at High Momentum Transfer ⋆

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Abstract

The E02013 collaboration's precision measurement of the electric form factor of the neutron at high momentum took place in Hall A of Jefferson Laboratory [1]. Four kinematic points spread in Q^2 from 1.2 up to 3.5 $(GeV/c)^2$ reach the region of momentum transfer where there is little ambiguity that the form factors are dominated by the valence quarks. The electric form factor provides important information for understanding the generalized parton distributions (GPDs) of the nucleon and therefore to understand the currently unknown quark angular orbital moments.

This report will present newly obtained results for G_E^n including at a Q^2 of 2.5 $(GeV/c)^2$ for the first time. Our data provide access to twice the range of momentum transfer for complete iso-spin decomposition of the nucleon form factors. The form factors of the u and d quarks will be presented. We extracted the charge density as a function of the impact parameter, which together with deep inelastic electron scattering data provides a three dimensional tomographic picture of the neutron [2].

Measurement was done by using the double polarization asymmetry method [3][4] utilizing ^{3}He with polarization of up to 55% (provided by a novel hybrid optical pumping scheme utilizing a Rb & K mixture) and the highly polarized (85%) electron beam provided by Jefferson Laboratory. A specially constructed detector consisting of an electron spectrometer, named Big Bite, with a solid angle of 95 msr and a large neutron detector were used to detect the particles in the reaction $^3\overrightarrow{He}(\vec{e}, e'h)$. The experimental apparatus provided more than 100 times better Figure-of-Merit than other G_E^n experiments utilizing polarized targets, for more information see [5].

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1. Neutron Form Factors

The deviation of nucleon structure from pointlike behavior can be described in terms of form factors. Using form factors, the nucleon current can be written as:

$$J^{\mu} = \bar{u}(k') \left[\gamma^{\mu} F_1(Q^2) + \frac{i}{2M} \sigma^{\mu\nu} q_{\nu} F_2(Q^2) \right] u(k) \ , \tag{1}$$

where $F_1 = \frac{G_E + \tau G_M}{1+\tau}$ and $F_2 = \frac{G_M - G_E}{1+\tau}$ are the Dirac and Pauli form factors related through the Sachs form factors G_E and G_M. Here $\tau = \frac{Q^2}{4M^2}$. From this an asymmetry can be formed that depends only on the form factor ratio and the kinematic coefficients:

$$A = \frac{-\frac{\mathbf{G_E}}{\mathbf{G_M}} B \sin\theta^* \cos\phi^* + C \cos\theta^*}{\left(\frac{\mathbf{G_E}}{\mathbf{G_M}}\right)^2 + D} \ , \tag{2}$$

where $B = 2\sqrt{\tau(1+\tau)} \tan\left(\frac{\theta_e}{2}\right)$, $C = -2\tau\sqrt{1+\tau+(1+\tau)^2 \tan^2\left(\frac{\theta_e}{2}\right)} \tan\left(\frac{\theta_e}{2}\right)$, and $D = \left(\tau + 2\tau(1+\tau)\tan^2\left(\frac{\theta_e}{2}\right)\right)$. The polarization angles of the target are θ^* and ϕ^* and θ_e being the scattered electron angle.

2. High Q^2 Measurement

In the double polarization technique, polarized electrons scatter from polarized ^{3}He. The final hadron and electron are detected in the process $^3\overrightarrow{\mathrm{He}}(\vec{e}, e'n)pp$. The precision of this measurement was increased by the developement of new target techniques and improvement of the beam, which yielded high polarization in both and high luminosity. To increase statistics, a large electron spectrometer with constructed matching neutron detector were used as shown in figure 1.

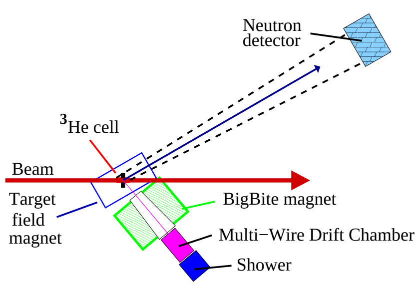

Fig. 1. Concept of the experimental setup.

After interaction with the target, the scattered electrons then travelled through the Big Bite magnet, through a multi-wire drift chamber, and finally into a calorimeter. The trigger for data collection was formed from a signal in the calorimeter in coincidence with a signal with sufficient amplitude of the recoiling hadron. This recoiling hadron was detected in 7 layers of hadron counters which made up the neutron arm along with 2 veto layers.

Hadron events were selected so that they are in time and parallel to $\vec{q}$. Quasi-elastic events were identified using the invariant mass, with the charge of the hadron determined using the veto counters. To supress Final State Interactions (FSI), only events with small perpindicular missing momentum, $\vec{p}_{m,\perp} = \hat{q} \times \vec{p}_m$, were selected.

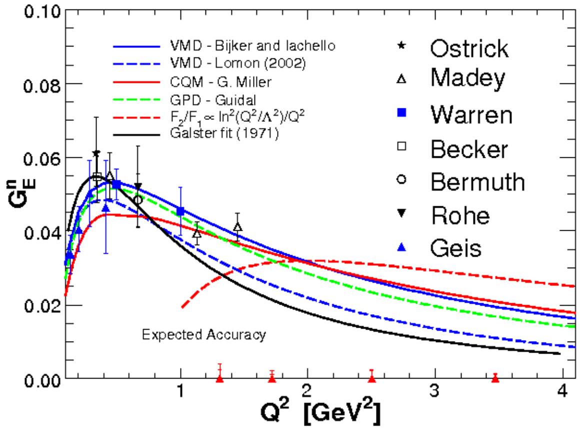

Fig. 2. Representative published data on G_E^n and selected set of theoretical predictions.

Preliminary values for the electric form factor have been determined for the kinematics at Q^2=1.7, 2.5, and 3.4 (GeV/c)^2. Shown in figure 2 are the locations of the E02-013 data points and the obtained accuracy in addition to published data points and selected models. The relative accuracy of the E02-013 data points is about 25%.

As is shown here, the E02-013 measurement more then doubles the range of Q^2 covered. This allows great discriminating power in determining which models describe the nucleon structure best. Preliminary results indicate a result of G_E^n that is smaller than many models predict. The momentum transfer covered increases the range over which the Pauli and Dirac form factors can be deconvoluted, and from these, the flavor form factors can be calculated. These are given as (neglecting the strange form factor):

$$F_{1,2}^n = e_d F_{1,2}^u + e_u F_{1,2}^d \ , \ F_{1,2}^p = e_u F_{1,2}^u + e_d F_{1,2}^d \ . \tag{3}$$

In the GPD framework, the flavor form factors can be expressed as the integral over all x (the longitudinal momentum fraction) of the generalized parton distributions ($H^q(x,\xi,t)$, $E^q(x,\xi,t)$). In some models of the GPDs like that by Guidal et al., parameters for the description of $E^q(x,\xi,t)$ are dependent on the nucleon form factors[6]. New electric form factor data determines new parameters, and behavior of the GPDs. These GPDs can be related to the quark orbital angular momentum (L^q) via Ji's Sum Rule[7]:

$$2J^q = \Delta q + 2L^q = \int_{-1}^{1} dx x [H^q(x,0,0) + E^q(x,0,0)] \ . \tag{4}$$

Using a fit to our preliminary results, the down quark orbital angular momentum was observed to be larger then that of the previous fit.

References

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