Experiment E02-013: Measurement of the Electric Form Factor of the Neutron at High Q^2

The G_E^n Experiment in Hall A at Jefferson Laboratory

Jefferson Lab
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JSA

Large Collaborative Effort

People

7 graduate students
5 postdocs
Over 100 collaborators

Funding

U.S. Department of Energy

National Science Foundation

Institutions

Core Institutions:

Jefferson Laboratory
University of Virginia
Yerevan Physics Institute
College of William and Mary
University of Kentucky
University of Maryland, College Park
Carnegie Mellon University
California State University, Los Angeles

Over 20 institutions in 7 countries

Nucleon Form Factors

The electromagnetic current for a general spin 1/2 particle with structure (such as the nucleon) is parameterized by the formula

$$J^\mu = e\bar{u}(p')\left[\frac{G_E\left(Q^2\right)+\tau G_M\left(Q^2\right)}{1+\tau}\gamma^\mu - \frac{iq_\nu\sigma^{\mu\nu}}{2M}\frac{G_E\left(Q^2\right)-G_M\left(Q^2\right)}{1+\tau}\right]u(p)$$

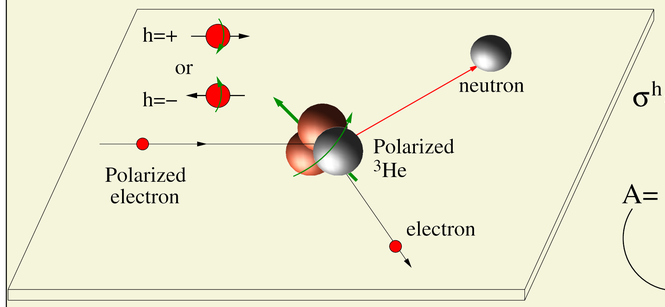
The electric form factor, G_E, and magnetic form factor, G_M, modify scattering from what it would be if the nucleon were pointlike (i.e. pointlike implies $G_E = 0$, $G_M = \mu$).

The ratio G_E/G_M can be accessed by measuring the cross section asymmetry by scattering a polarized electron from a transversely polarized target.

$$A_\perp = \frac{\sigma_{\leftarrow\uparrow}-\sigma_{\rightarrow\uparrow}}{\sigma_{\leftarrow\uparrow}+\sigma_{\rightarrow\uparrow}} = -\frac{2\sqrt{\tau(\tau+1)}\tan(\theta/2)G_E/G_M}{(G_E/G_M)^2+(\tau+2\tau(1+\tau)\tan^2(\theta/2)}$$

This Hall A G_E^n measurement provides a charge weighted snapshot of the neutron with unprecedented resolution.

Polarized Electron Scattering from Polarized ^{3}He



Rates

$\sigma^h = \sigma_U + h\sigma_P$

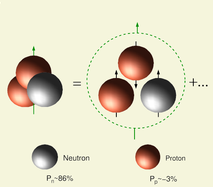
$A = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-}$

$\frac{G_E}{G_M}$

Measuring the helicity dependent cross section asymmetry from the reaction $^3\overrightarrow{\mathrm{He}}(\vec{e},e'n)pp$ gives a sensitive method to access the ratio G_E/G_M of the neutron.

Experimental Setup

Polarized ^{3}He Target

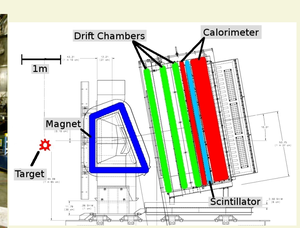


^{3}He nucleus spin is mainly carried by the neutron providing an effectively polarized neutron

Polarization by spin exchange optical pumping using Rb and K vapor.

Record sustained in-beam polarization of 50%

Electron Arm - BigBite Spectrometer

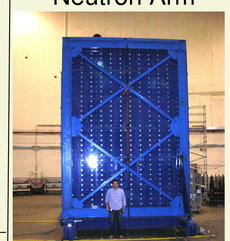


BigBite is a large angular and momentum acceptance spectrometer consisting of a large dipole magnet with a solid angle of 100 msr and associated detector stack.

Electron tracking is performed through a set of high resolution drift chambers and provides a momentum resolution of $\sigma_{(\delta p/p)} \approx 1\%$

Operates in an open environment with a high luminosity of 10^{37} Hz/cm^2

Neutron Arm

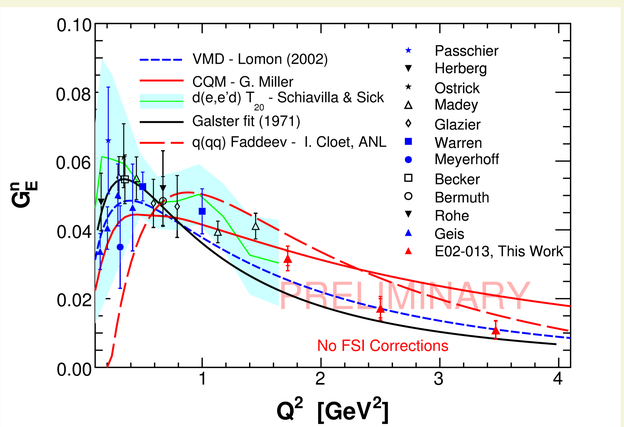


Large array of scintillator with over 500 PMTs and active area of about 10m^2 provides detection of recoiling nucleons.

Momentum measured through time of flight with resolution $\sigma_{\mathrm{time}} \approx 0.4$ ns

Nucleon charge differentiation performed through veto planes.

Results



Preliminary results measured at three Q^2 points from 1.7 to 3.5 GeV^2.

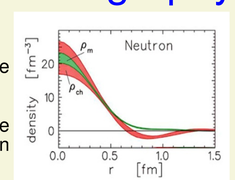
These new data doubles the Q^2 range where it had been previously measured providing high resolution "snapshot" on the charge structure of the neutron.

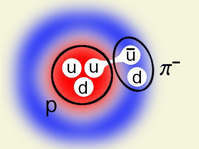
Nucleon Tomography

Classical Picture

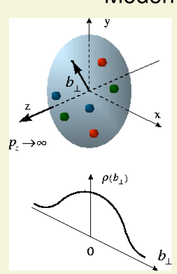
G_E gives information on RMS charge radius in its rest frame.

Neutron charge RMS radius is negative suggesting a partial picture of a proton surrounded by a π^- cloud

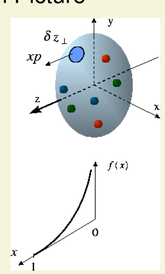




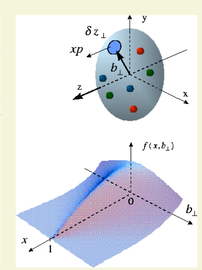
Modern Picture



Form Factors
Transverse Density



DIS
Longitudinal Density



GPD
Unified Description

Generalized Parton Distributions (GPDs) provide a unifying method of combining transverse structure from form factors and longitudinal structure from DIS