THE CHARGE FORM FACTOR OF THE NEUTRON AT LOW Q^2 *

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THE BLAST COLLABORATION

Measurement of the charge form factor of the neutron G_E^n presents a sensitive test of nucleon models and QCD-inspired theories. In particular, the pion cloud is expected to play a dominant role in the low-momentum transfer region of G_E^n. At the MIT-Bates Linear Accelerator Center, G_E^n has been measured by means of quasielastic scattering of polarized electrons from vector-polarized deuterium, $^2\vec{\mathrm{H}}(\vec{\mathrm{e}},\mathrm{e'n})$. The experiment used the longitudinally polarized stored electron beam of the MIT-Bates South Hall Ring along with an isotopically pure, highly vector-polarized internal atomic deuterium target provided by an atomic beam source. The measurements have been carried out with the symmetric Bates Large Acceptance Spectrometer Toroid (BLAST) with enhanced neutron detection capability. From the beam-target double polarization asymmetry A_{ed}^V with the target spin oriented perpendicular to the momentum transfer the form factor G_E^n is extracted over a range of four-momentum transfer Q^2 between 0.12 and 0.70 $(\mathrm{GeV/c})^2$ with minimized model dependencies.

1. Introduction

The electromagnetic form factors of the nucleon provide basic information on nucleon structure. At low momentum transfer, the pion cloud of the nucleon is expected to play a significant role in the quantitative description of the form factors, in particular for the electric form factor of the neutron G_E^n in the absence of a net charge. Thus, the low-Q^2 region of G_E^n is an ideal testing ground for QCD- and pion-cloud inspired and other effective nucleon models. In the nonrelativistic framework, the Fourier transform of G_E^n can be interpreted as the charge distribution of the neutron in the Breit frame. The spatial distribution indicates that the neutron consists of a positively-charged core surrounded by a negatively charged cloud.

Among the four non-strange nucleon electromagnetic form factors, the electric form factor of the neutron G_E^n is experimentally the least known one with uncertain-

*This work is supported by DOE under Cooperative Agreement DE-FC02-94ER40818

ties of typically 15-20%. Significant improvement of the experimental uncertainty is highly desirable and is setting strong constraints for nucleon models. A precise knowledge of G_E^n at low Q^2 is also essential to reduce the systematic errors of parity violation experiments.

In the past, experimental access to G_E^n was hampered by the absence of free neutron targets, and the extraction of G_E^n from elastic electron-deuteron scattering appeared to be largely model-dependent. This difficulty has been overcome in recent years with the advent of polarized beams and targets which minimize both the systematic errors and the model dependency. This work reports about a new measurement of G_E^n over a range of four-momentum transfer Q^2 between 0.12 and 0.70 (GeV/c)^2 with the BLAST experiment at the MIT-Bates Linear Accelerator Center. The technique makes use of quasielastic scattering of polarized electrons from vector-polarized deuterium in the $^2\vec{\mathrm{H}}(\vec{\mathrm{e}},\mathrm{e'n})$ reaction. The asymmetry is sensitive to the electric to magnetic form factor ratio of the neutron G_E^n/G_M^n in a kinematics where the target spin is oriented perpendicular to the momentum transfer vector $\vec{q}$. In Plane Wave Impulse Approximation (PWIA) the beam-vector asymmetry is given by

$$\frac{1}{hP_z} A_{ed}^V = \frac{a\, {G_M^n}^2 \cos\theta^* + b\, G_E^n G_M^n \,\sin\theta^* \cos\phi^*}{c\, {G_E^n}^2 + {G_M^n}^2} \approx a\, \cos\theta^* + b\, \frac{G_E^n}{G_M^n}\, \sin\theta^* \cos\phi^*, \quad (1)$$

where θ^* and ϕ^* describe the target spin orientation with respect to the momentum transfer direction and a, b, c are kinematical factors. The term hP_z denotes the product of beam and target polarization.

2. The BLAST Experiment

The BLAST experiment has been designed to measure spin-dependent electron scattering at intermediate energies from polarized targets in the elastic, quasielastic and resonance region. Based on the internal target technique BLAST optimizes the use of a longitudinally polarized electron beam stored in the South Hall Ring of the MIT-Bates Linear Accelerator Center, in combination with an isotopically pure, highly-polarized internal target for both hydrogen or deuterium. In case of deuterium the target was both vector and tensor polarized. The polarized target is provided by an atomic beam source (ABS). The ejected gas molecules are first dissociated into atoms before they pass sections of sextupole magnets and RF transition units to populate the desired single spin states through Stern-Gerlach beam splitting and induced transitions between hyperfine states (see left hand side of Fig. 1). This selection process is highly efficient and thus provides nuclear polarizations of more than 70%. The spin state selection was altered every five minutes in a random sequence to minimize systematics. The polarized atoms are injected into a 60 cm long cylindrical target cell with open ends through which the stored electron beam passes. As there are no target windows the experiment is very clean with negligibly small background rates of only a few percent in the prominent channels.

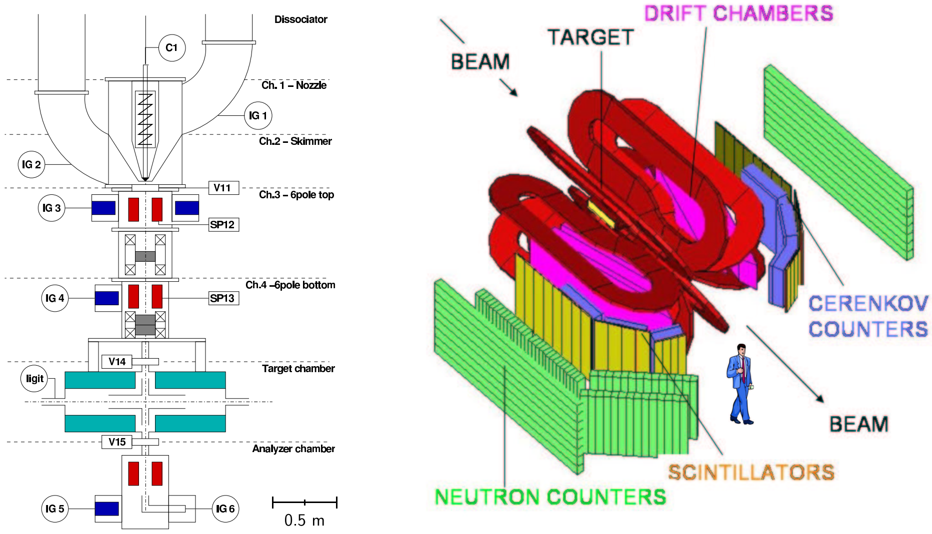

Figure 1. Schematics of the Atomic Beam Source (left) and the BLAST detector (right).

The direction of the target spin can be freely chosen within the horizontal plane using magnetic holding fields. During BLAST data taking, the spin direction pointed at 32° and 47° to the left side of the beam axis in the 2004 and 2005 runs, respectively. At Bates beam currents of up to 225 mA were stored in the ring at 65% polarization and beam lifetimes of 20-30 minutes. The electron beam energy was 850 MeV throughout the BLAST program. The relatively thin target in combination with the high beam intensity yields a luminosity of about $5 \times 10^{31}/(\mathrm{cm}^2\,\mathrm{s})$ at an average current of 175 mA. The Bates storage ring contains a Compton polarimeter to monitor the longitudinal beam polarization in real time and without affecting the beam. The electron spin precession is compensated with a spin rotator (Siberian snake) in the ring section opposite of BLAST. The helicity of the beam was flipped once before every ring fill.

The BLAST detector is schematically shown in the right hand side of Figure 1. It was built as a toroidal spectrometer consisting of eight normal-conducting copper coils producing a maximum field of 3800 G. The two in-plane sectors opposing each other are symmetrically equipped with drift chambers for the reconstruction of charged tracks, aerogel-Cerenkov detectors for e/π discrimination and 1" thick plastic scintillators for timing, triggering and particle identification. The angular acceptance covers scattering angles between 20° and 80° as well as ±15° out of plane. The symmetric detector core is surrounded by thick large-area walls of plastic scintillators for the detection of neutrons using the time-of-flight method. The thin scintillators in combination with the volumimous wire chambers in front of the neutron detectors were used as a highly efficient veto for charged tracks, making the selection of (e,e'n) events extremely clean. The setup allows to simultaneously measure the inclusive and exclusive channels (e,e'), (e,e'p), (e,e'n), (e,e'd) elastic or quasielastic, respectively, as well as (e,e'π) in the excitation region of the Δ resonance. By measuring many reaction channels at the same time over a broad range of momentum transfer, the systematic errors are minimal.

The neutron detectors are enhanced in the right sector with $\approx$ 30% neutron detection efficiency ($\approx$ 10% in the left sector). The reason for this is because of the choice of the target spin orientation. For electrons scattered into the left sector of BLAST, the momentum transfer vector is approximately perpendicular to the target spin direction where the sensitivity to the neutron electric to magnetic form factor ratio is maximal, as can be seen from Eq. (1). In the opposite case with electrons scattered into the right sector, the spin angle is approximately parallel to $\vec{q}$ which serves as a calibration process from which the product of beam and target polarization hP_z can be extracted. A more precise value of the polarization product is however obtained from evaluating the beam-vector asymmetry A^V_{ed} of the $^2\vec{\mathrm{H}}(\vec{\mathrm{e}}$,e'p) reaction at low Q^2 and low missing momentum (see contribution by R. Alarcon in these proceedings). For the 2004 run of BLAST, a value of $hP_z = 0.558 \pm 0.009(stat.) \pm 0.006(sys.)$ has been determined corresponding to a deuteron vector polarization of 86%.

3. Preliminary results

From the measured (e,e'n) yields in each beam-target spin state combination normalized to the collected deadtime-corrected beam charge the experimental double spin asymmetry A^V_{ed} is formed. For five bins in Q^2, the experimental asymmetry as a function of missing momentum is compared with the full BLAST Montecarlo result based on deuteron electrodisintegration cross section calculations by H. Arenhövel[1] with consistent inclusion of reaction mechanism und deuteron structure effects. In the quasielastic limit of the $^2\vec{\mathrm{H}}(\vec{\mathrm{e}}$,e'n) reaction, the deviation from PWIA is dominated by final-state interaction which increases towards lower Q^2 but is reliably calculable in the whole Q^2 range covered by the experiment. Relativistic effects are accounted for as first-order corrections which are very small in the low-Q^2 region. The electric form factor of the neutron is varied as an input parameter to the Montecarlo simulation and its measured value is extracted by a χ^2 minimization for each Q^2 bin.

Figure 2 (l.h.s.) shows the preliminary result for G^n_E from the 2004 run of BLAST along with the world data from polarization experiments[2]. Also shown is the parameterization by Galster *et al.*[3] (G) $G^n_E = 1.91\tau/(1 + 5.6\tau)G_{Dipole}$ where $\tau = Q^2/(4M^2_n)$. The excess of the data over the Galster curve at high and at low Q^2 is better accounted for by the more recent parameterization by Friedrich and Walcher[2,4] (FW), who describe all four nucleon form factors as sums of a smooth and a bump part, where the latter is attributed to the role of the pion cloud around the nucleon. The new preliminary BLAST data is quite consistent with both the bulk of existing data as well as with the parameterizations shown in Fig. 2, of which

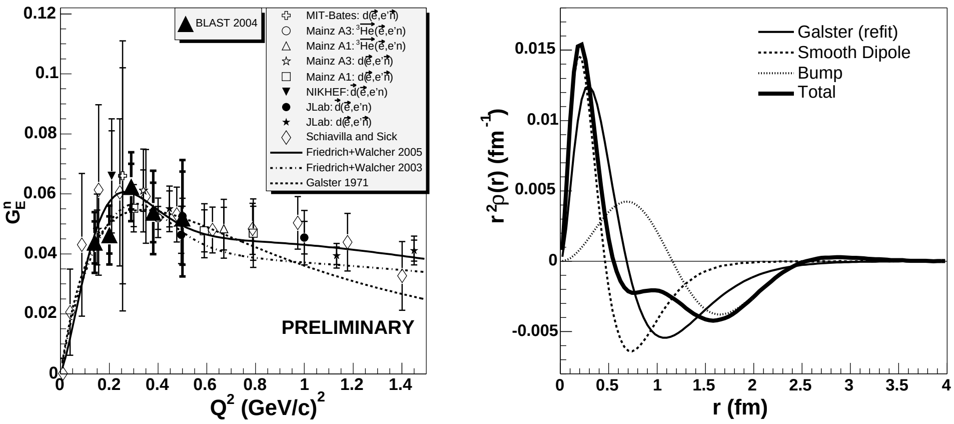

Figure 2. L.h.s: Electric form factor of the neutron from polarization experiments[2] along with preliminary results from BLAST. The curves are the original parameterization by Galster[3] *et al.* and the recent parameterizations by Friedrich and Walcher[2,4]. R.h.s.: Fourier transforms of G_E^n of the refitted parameterizations after including preliminary data from BLAST. The excess at low Q^2 accounted for by the new parameterization corresponds to a spatial distribution that extends to larger radii than the one obtained by the Galster parameterization.

the FW parameterization appears slightly favored. Note that the BLAST data is preliminary and based on only about half of the statistics that were acquired in the total run in 2004 and 2005.

The form factor as given in momentum space can be Fourier-transformed to obtain spatial distributions. Although recently the interpretation of the nucleon form factors in r-space has been under debate, in the Breit frame the result can be interpreted as the distribution of the charge density of the neutron, which is particularly valid at low Q^2 where the Breit and the neutron rest frames are very close. Fitting the G and FW parameterizations to the world data from polarization measurements[2] including the BLAST results, yields the spatial distributions shown in the right hand side of Fig. 2. The bump in the form factor distribution at low Q^2 causes the negative part of the charge distribution to extend out to larger radii than suggested by the previous Galster parameterization.

The preliminary results shown here comprise parts of a PhD thesis[5] based on the BLAST data taken in 2004. Analysis of the full 2004-2005 dataset is in progress[6].

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