Nucleon Form Factors from BLAST

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Abstract. The BLAST (Bates Large Acceptance Spectrometer Toroid) experiment has been carried out at the MIT-Bates Linear Accelerator Center to study spin-dependent electron scattering from protons and deuterons with small systematic uncertainties. The experiment used a longitudinally polarized, intense electron beam stored in the Bates South Hall Ring in combination with isotopically pure, highly-polarized internal targets of polarized hydrogen and vector- and tensor-polarized deuterium from an atomic beam source. The BLAST data have been used to extract precise results for the elastic form factor ratios G_E/G_M of the proton and the neutron at low momentum transfer.

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Measurements of the elastic form factors of the proton and neutron and their theoretical descriptions have long been and continue to be a focus of modern nuclear physics. The BLAST (Bates Large Acceptance Spectrometer Toroid) experiment at the MIT-Bates Linear Acelerator Center was designed specifically to fully exploit polarization degrees of freedom in electron scattering in a systematic study of elastic nucleon and deuteron form factors, quasielastic deuteron electrodisintegration, and inelastic electron scattering in the Δ resonance region. The experimental configuration was the first to use an electron storage ring with longitudinally polarized beam and internal polarized hydrogen and vector- and tensor-polarized deuterium target supplied by an atomic beam source (ABS) in combination with a large-acceptance magnetic spectrometer.

Precise single and double polarization observables in inclusive scattering (e,e') along with the exclusive channels (e,e'p), (e,e'n), (e,e'd) und (e,e'π) were measured simultaneously with the BLAST detector, in order to extract e.g. the proton electric to magnetic form factor ratio G_E^p/G_M^p, the form factors of the neutron G_E^n and G_M^n, electromagnetic structure observables of the deuteron such as the tensor analyzing power T_{20} or the structure functions of the quasielastic deuteron breakup as well as pion electroproduction in the Δ resonance region.

The BLAST detector is a toroidal spectrometer with eight normal-conducting magnetic coils producing a maximum field of 0.38 T. The two opposite in-plane sectors were instrumented symmetrically with detectors to track charged particles and neutrons. The angle acceptance covered scattering angles between 20° and 80° as well as up to $\pm 15^\circ$ out of plane. The South Hall Ring (SHR) was periodically filled with ~ 200 mA of polarized electrons at 850 MeV. The beam polarization P_b of $\sim$66% was kept longitudinal at the interaction point with the help of spin rotators (Siberian Snake) in the opposite straight section of the SHR and was monitored continually with a Compton backscattering polarimeter. The ABS provided hydrogen or deuterium atoms in separate nuclear spin states with a proton polarization $P_t \sim 83\%$ and a deuteron vector (tensor) polarization of up to 89% (68%). The target spin direction was aligned with Helmholtz coils and

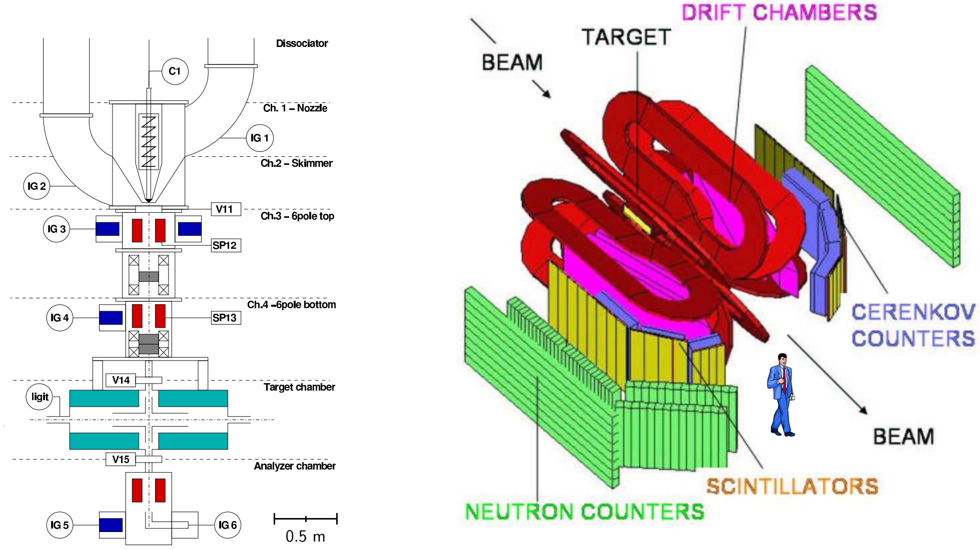

FIGURE 1. Schematic view of the Atomic Beam Source (left) and the BLAST detector (right).

carefully mapped, resulting in average values of 48.0° for the ^{1}H(e,e’p) and to 31.6° and 46.3° for the ^{2}H(e,e’n) event samples, relative to the beam direction into the left sector of BLAST. The ABS and the BLAST detector are shown schematically in Fig. 1. Details of the BLAST experimental setup can be found in [1].

With longitudinally polarized electron beam and polarized free-nucleon target, the spin-dependence of the elastic scattering cross section leads to a beam-target double asymmetry that is sensitive to the ratio of electric and magnetic form factors $G_E(Q^2)$ and $G_M(Q^2)$, viz.

$$A = -P_b P_t \, \frac{v_z \cos\theta^* + v_x \sin\theta^* \cos\phi^* G_E/G_M}{(\tau + \varepsilon (G_E/G_M)^2) \, / \, [\varepsilon(1+\tau)]}, \tag{1}$$

where θ^* and ϕ^* are the polar and azimuthal angles of the target polarization relative to the three-momentum transfer direction and $\tau = Q^2/(4M^2)$ with the nucleon mass M. The quantity $\varepsilon = [1 + 2(1+\tau)\tan^2(\theta_e/2)]^{-1}$ is known as the virtual photon polarization, where θ_e is the electron scattering angle, and $v_z = 2\tau \tan(\theta_e/2)\sqrt{1/(1+\tau) + \tan^2(\theta_e/2)}$, $v_x = 2\tan(\theta_e/2)\sqrt{\tau/(1+\tau)}$ are kinematic factors. Note that with the normalization $G_M(0) = \mu$, the nucleon magnetic moment, the “perpendicular” term $\propto \sin\theta^*$ alters its sign between protons ($\mu_p \simeq 2.79$) and neutrons ($\mu_n \simeq -1.91$). Also, with $G_E^n << G_E^p$, the magnitude of this term is quite different for protons and neutrons.

The elastic beam-target asymmetry has been measured with polarized protons for Q^2 between 0.15 and 0.65 (GeV/c)^2 in eight bins, each for two spin angle configurations simultaneously using the left-right symmetry of the setup. The kinematics of BLAST is such that the asymmetry with electrons scattered into the left (right) sector corresponds to $\theta^* \sim 90°$ ($\sim 0°$). The coincident elastic events were selected based on redundant kinematic information. The two asymmetry measurements in each Q^2 bin allows one to

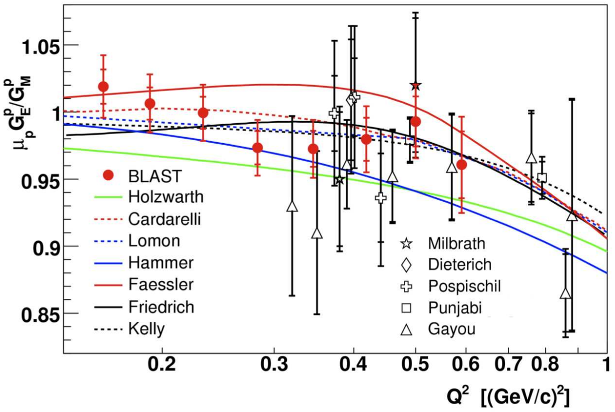

FIGURE 2. Results of $\mu_p G_E^p/G_M^p$ shown with the world polarized data [3] and several models [4, 5, 6, 7, 8, 9, 10].

extract both P_bP_t and $\mu_p G_E^p/G_M^p$ for each bin. However, since P_bP_t did not exhibit any Q^2 dependence, as expected, only one value for P_bP_t was extracted in a fit procedure together with $\mu_p G_E^p/G_M^p$ in all bins, thereby maximizing the information used toward extracting the form factor ratio. The BLAST results [2] are shown in Fig. 2 along with previous recoil polarization experiments [3] and various models [4, 5, 6, 7, 8, 9, 10]. In the Q^2 region below 0.3 (GeV/c)^2 the BLAST data mark the first measurements of $\mu_p G_E^p/G_M^p$ from a double polarization observable. In the overlap region with previous experiments the precision of the available data has been significantly improved.

Due to the lack of free neutron targets, any information on neutrons must be extracted from light nuclei such as the deuteron or ^{3}He. Instead of elastic electron-neutron scattering one has to consider e.g. quasielastic scattering in the ^{2}H(e,e'n) reaction. For nucleons in the *S* state, the nucleon spin is aligned with that of the vector-polarized deuteron. Nuclear corrections have to be applied for final state interactions (FSI), meson exchange currents (MEC), isobar configurations (IC) and relativistic corrections (RC), for which the electrodisintegration model of [11] has been used. The neutron elastic form factor ratio $\mu_n G_E^n/G_M^n$ has been determined with BLAST for Q^2 between 0.10 and 0.55 (GeV/c)^2 applying the model framework in a Montecarlo simulation of the experiment. The size of FSI correction at low Q^2 is substantial and its validity has been independently verified with the simultaneously measured tensor asymmetry, which is dominated by FSI and in good agreement with the data [12]. The neutron electric form factor was extracted assuming a parameterized form for G_M^n taken from [9]. The results are shown in Fig. 3. The new data from BLAST [12] significantly improve the data quality at low Q^2 and remove the large model uncertainty of G_E^n when extracted from elastic electron-deuteron scattering. The data agree very well with recent VMD fits [6, 18] and show no evidence for any narrow structure in Q^2.

Further analyses of BLAST data are in progress and will yield further form factor results on G_E^p/G_M^p from $^2\vec{\mathrm{H}}(\vec{\mathrm{e}},\mathrm{e'p})$, and on G_M^n from the $^2\vec{\mathrm{H}}(\vec{\mathrm{e}},\mathrm{e'})$ inclusive channel.

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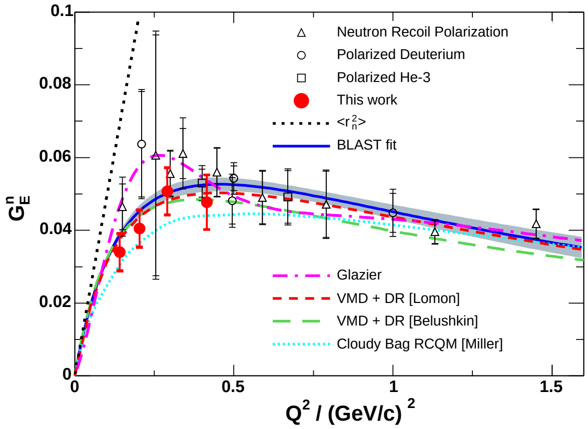

FIGURE 3. Results on G_E^n from BLAST [12] shown along with the world data from neutron recoil polarization experiments with unpolarized ^{2}H target [13] (open triangles) and experiments with polarized ^{2}H (open circles = Ref. [14]) and ^{3}He targets [15] (open squares), and with various model curves [16, 17, 9, 6, 18, 19].

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