Spin Dependent Electron Scattering with the BLAST detector

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The Bates Large Acceptance Spectrometer Toroid experiment, BLAST, at the MIT-Bates Linear Accelerator Laboratory was designed to study in a systematic manner the spin-dependent electro-magnetic interaction in few-nucleon systems at momentum transfers below 1 GeV/c. Utilizing a polarized electron beam; highly polarized, internal gas targets of H and D; and a symmetric detector configuration: BLAST is able to make simultaneous measurements of several reaction channels for different combinations of beam helicity and target polarization (vector for H, both vector and tensor for D). BLAST will provide new data on the nucleon and deuteron form factors as well as study few body physics and pion production. Preliminary results are presented.

1. Spin-dependent Electron Scattering

The general form for the differential cross section in the exclusive scattering of longitudinally polarized electrons from a polarized target is given by [1]

$$\frac{d\sigma}{de' d\Omega'_e d\Omega_N} = \Sigma + h\Delta \tag{1}$$

where h is the helicity of the incident electron, and Σ and Δ are the helicity-sum and helicity-difference cross sections, respectively. The kinematic variables and coordinate system for electron-hadron coincidence reactions with polarized incident electrons and polarized nuclear target are shown in Fig. 1. The Σ and Δ cross sections for the case of elastic scattering from a polarized nucleon can be written as

$$\Sigma = c(\rho_L G_E^2 + \rho_T \frac{q^2}{2M^2} G_M^2) \tag{2}$$

and

$$\Delta = -c(\rho'_{LT} \frac{q}{2^{3/2}M} G_E G_M P_x + \rho'_T \frac{q^2}{2M^2} G_M^2 P_z) \tag{3}$$

where c is a kinematical factor, the ρ's are the virtual photon densities, and P_j indicates the polarization of the nucleon along each of the three coordinate axes, of which the z-axis has been chosen parallel to $\vec{q}$.

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The electric, G_E^p, and magnetic, G_M^p, proton form factors are known, over a wide range of Q^2, from Rosenbluth separations of the Σ cross section.[3] A knowledge of the Δ part of the cross section is relevant when one intends to measure the form factor G_E^n for the neutron.[3] The non-existence of pure neutron targets requires that G_E^n be measured from scattering from a bound neutron in a nuclear target. Moreover, since G_E^n is very small it is necessary to measure the Δ cross section in order to access the interference term. Experimentally one measures spin asymmetries defined as

$$A_{exp} = p_e p_T \frac{\Delta}{\Sigma} \tag{4}$$

where p_e and p_T are the electron beam and target polarization, respectively. When the target spin is oriented perpendicular (parallel) to the direction of $\vec{q}$ (i.e., selecting P_x (P_z)) one isolates different terms of the Δ cross section. In this way the spin can be used to separate the different response functions. Complementary information is found in each of the terms proportional to the polarization P_j. To achieve the desired statistics in the determination of the above asymmetries, data taking runs of typically several hundred hours are needed. A goal is to keep the overall systematic uncertainty in A_{exp} comparable to the statistical uncertainty.

2. The BLAST Experiment

The MIT-Bates linear accelerator consists of a 500 MeV linac with recirculator to produce electrons with energies up to 1 GeV and polarizations of $\sim$ 70%. The BLAST experiment is situated on the South Hall Storage Ring. Injected currents of $\sim$ 175 mA with lifetimes of $\sim$ 25 minutes are typical. A Siberian snake maintains the longitudinal polarization of the stored electron beam and a Compton polarimeter is used to monitor the stored beam polarization.

The BLAST detector (Figure 2) is based on an eight sector, toroidal magnet with a maximum field of $\sim$ 3800 G. The detectors in the left and right, horizontal sectors nominally subtend 20°–80° in polar angle and $\pm 15°$ azimuthally. The detector is roughly symmetric with each sector containing: wire chambers for charged particle tracking, Čerenkov detectors for electron identification, and time of flight scintillators to measure the relative timing of scattered particles. The neutron detectors are somewhat asymmetric with the right sector having a greater thickness.

In each sector three wire chambers are combined into a single gas volume. Each chamber has two super-layers of drift cells with three planes of sense wires. The sense wires are inclined $\pm 5°$ to the vertical to permit reconstruction in three dimensions. Currently, momentum resolutions around 3%, angular resolutions of 0.5°, and vertex resolutions of 1 cm have been obtained.

The Čerenkov detectors use 1 cm thick Aerogel tiles ($n \approx 1.023$) inside 5 cm thick boxes painted with a white reflective paint. Readout is by 5″ diameter PMT's at the top and bottom of the boxes and an efficiency greater than 85% is achieved.

The time of flight (TOF) detectors consist of sixteen vertical scintillator bars 1″ thick and 8″ wide with PMT's at top and bottom. Timing resolutions of 300 ps are typical.

Each sector has eight horizontal, 10 cm thick, 22.5 cm wide, and 400 cm long scintillator bars for neutron detection. Additional vertical scintillators in the right sector improve detection efficiency. All bars are read out by PMT's at both ends.

An atomic beam source is used to produce highly polarized targets of pure hydrogen or deuterium. Combinations of magnets and RF transition units populate and transport the desired spin states into a 15 mm diameter, 60 cm long, thin aluminium cylinder open at either end through which the electron beam passes. For deuterium, a target thickness of 6×10^{13} atoms/cm^2 with polarizations of 72% vector or 68% tensor are typical. A magnetic holding field of ~ 500 G defines the target spin angle. This is typically horizontal, at 32° into the left sector so an electron scattering to the left (right) corresponds to a momentum transfer roughly perpendicular (parallel) to the spin angle.

The data acquisition uses the CODA and trigger supervisor systems from TJLAB. This allows multiple triggers to be defined so data can be accumulated for elastic, quasi-elastic, inclusive, and production reactions at the same time. Data are collected reversing the beam helicity each fill and randomly cycling through the target spin states every five minutes.

3. Scientific Program

One of the central scientific goals of BLAST is to provide precise information on nucleon form factors for squared momentum transfers up to about 0.8 (GeV/c)^2. Measurements of nucleon form factors, such as the electric and magnetic form factors of the neutron, G_E^n and G_M^n, are important for the understanding of the structure of baryons in the non-perturbative QCD regime. Until recently a purely phenomenological parametrization by Galster has served as the best description of G_E^n data. Lately, calculations of G_E^n based on effective field theories of QCD became available. The neutron electric form factor provides a sensitive test of many of these models. Precision G_E^n and G_M^n data at low momentum transfer are essential to constrain theoretical calculations of nucleon structure.

The deuteron is a natural starting point for an investigation of the nuclear electromagnetic current. With BLAST precise measurements of the spin structure of the deuteron are possible. Effects such as final-state interactions, meson exchange currents, and the off-shell nature of the bound nucleon can be studied over the broad kinematic range provided by the BLAST detector. With a tensor polarized deuterium target BLAST provides precise data from elastic e-d scattering (T_{20}), up to the region of the first minimum of the charge form factor of the deuteron. In addition, data are obtained in the same experiment for the exclusive scattering channels.

Simultaneously BLAST carries out measurements of spin-dependent charged pion electroproduction on few-body systems from threshold to the Δ-resonance. Such studies are important for understanding the role of the nucleon resonance in few-body systems. BLAST allows reconstruction of the resonance from its π-nucleon decay channel.

With a polarized proton target and a polarized electron beam, BLAST studies the $N \rightarrow \Delta$ transition to isolate components beyond the dominant M1 transition and provides additional precise data on the proton form factors.

4. Preliminary Physics Results

The present data correspond to integrated luminosities of 13 pb^{-1} on hydrogen and 169 pb^{-1} on deuterium. The results are still preliminary and only some results will be presented here. Approximately five times more data will be collected by BLAST on hydrogen and 2–4 times more on deuterium.

Recent experimental results[4–6] for $\mu_p G_E^p/G_M^p$ using Rosenbluth separation show the ratio remaining flat and close to unity while measurements using polarization transfer show the ratio deceasing quite rapidly with Q^2. BLAST results from *ep* elastic scattering (Figure 3) will be below 1 $(\mathrm{GeV/c})^2$ and unlikely to support either case. However, by taking the ratio of left and right asymmetries, the results are independent of beam and target polarization and will yield precise data at low Q^2 providing useful information on the proton radius and details on the pion cloud in hydrogen. Preliminary results are shown in Fig. 3 with statistical errors only. Our effective statistics will increase by a factor of about 16 when all the hydrogen data are analyzed.

The deuteron has three elastic form factors: G_C, G_M, and G_Q. Previous experiments were unable to fully unfold the three form factors or had to perform difficult double scattering experiments to measure the polarization of the scattered deuteron. With a pure, polarized deuterium target available with both vector and tensor polarizations; BLAST can resolve all terms[1]. For example, existing data for T_{20} are shown in Figure 4 together with the preliminary BLAST measurements. Future BLAST running will improve the measurements significantly and help constrain the theoretical models. Other spin asymmetries: T_{21}, T_{11} and T_{10} will also be measured and used to unfold G_C, G_M, and G_Q.

The proton form factors G_E^p and G_M^p and the neutron form factor G_M^n are already reasonably well measured. BLAST will add to these measurements but the main contribution will be in measuring the neutron charge form factor G_E^n. Figure 5 shows the existing data for G_E^n with the preliminary data from BLAST. The neutron form factor is derived from studying the vector asymmetry of quasi-elastic *en* scattering from deuterium and utilises existing data on G_M^n. With the additional data the BLAST errors should be significantly reduced and the data extended to slightly higher Q^2. BLAST will also make a direct measurement of G_M^n by studying inclusive electron scattering from deuterium..

By studying quasi-elastic *ep* scattering from deuterium the D-state contribution and hence tensor force can be studied. In the Born approximation the tensor asymmetry for quasi-elastic scattering should be zero in the absence of D-state contributions. As seen in Figure 6 for both perpendicular and parallel kinematics a significant asymmetry is seen as the missing momenta increases indicating the onset of D-state contributions. Similar effects are seen in the vector asymmetries.

5. Conclusion

Preliminary data from BLAST are encouraging. Future BLAST data and further analysis should provide a wealth of data on nucleon and deuteron form factors and help to constrain the theoretical models.

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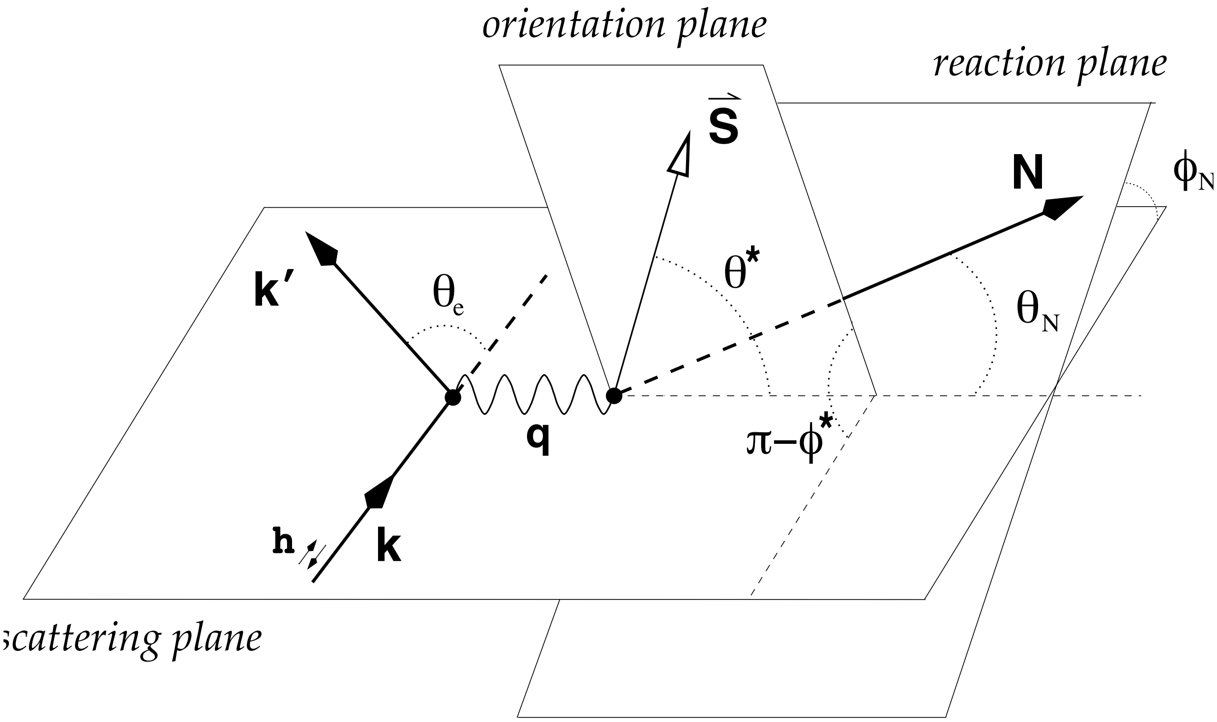

Figure 1. Kinematics and coordinate system for electron-hadron coincidence reactions with polarized incident electrons and polarized nuclear target. A reference frame xyz is defined in which the xz-plane is the scattering plane and the z axis is along $\vec{q}$.

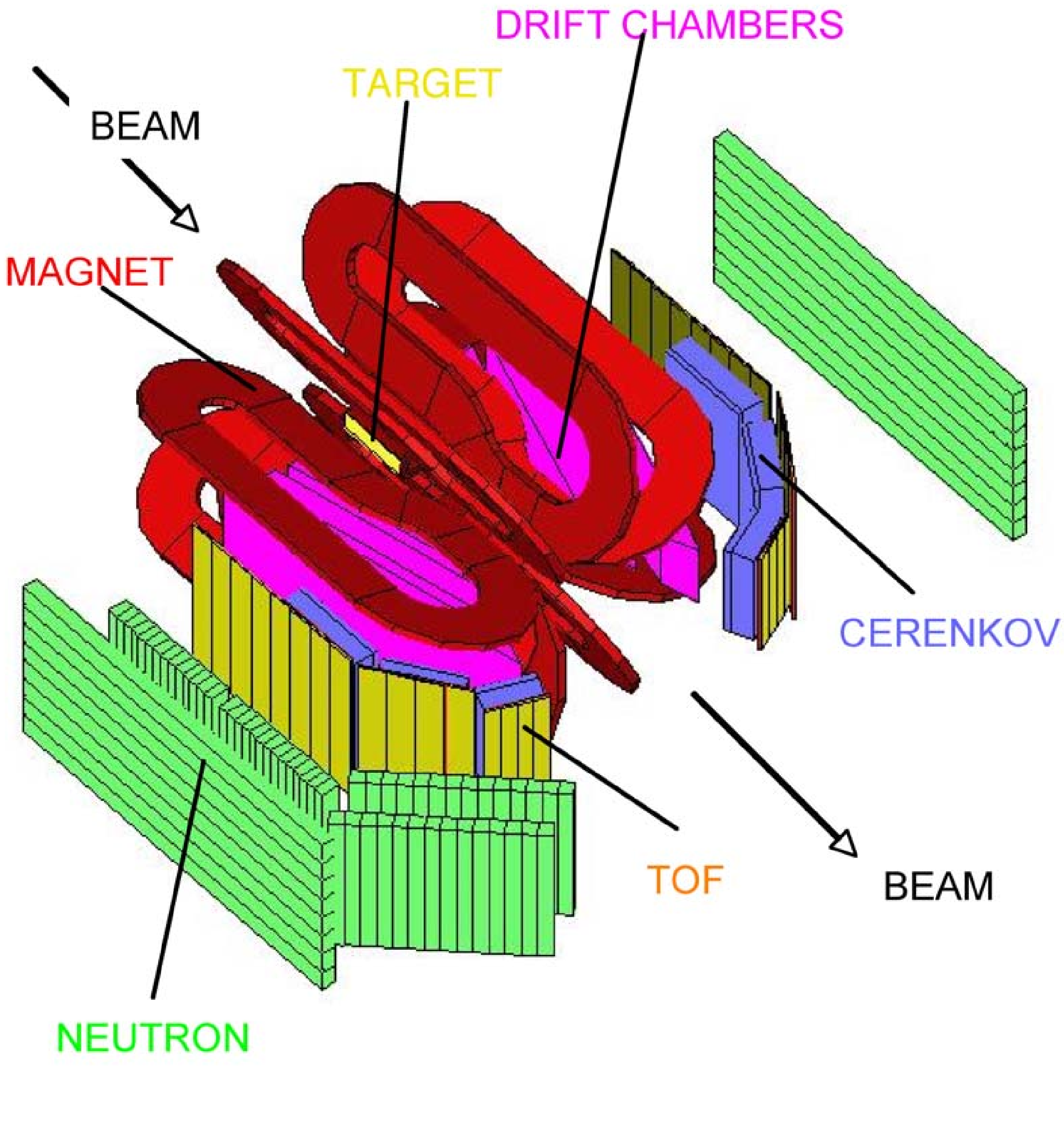

Figure 2. Schematic, isometric view of the BLAST detector showing the main detector elements.

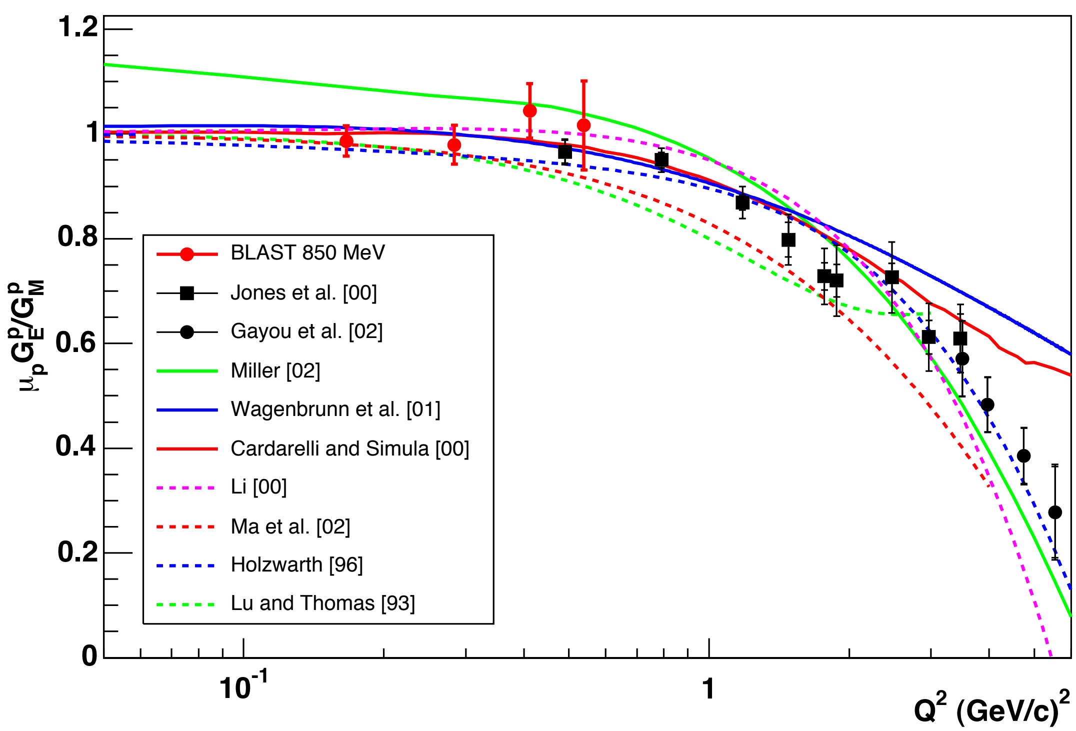

Figure 3. Preliminary results for the ratio $\frac{\mu_p G_E^p}{G_M^p}$ compared to existing world data and several theoretical predictions.

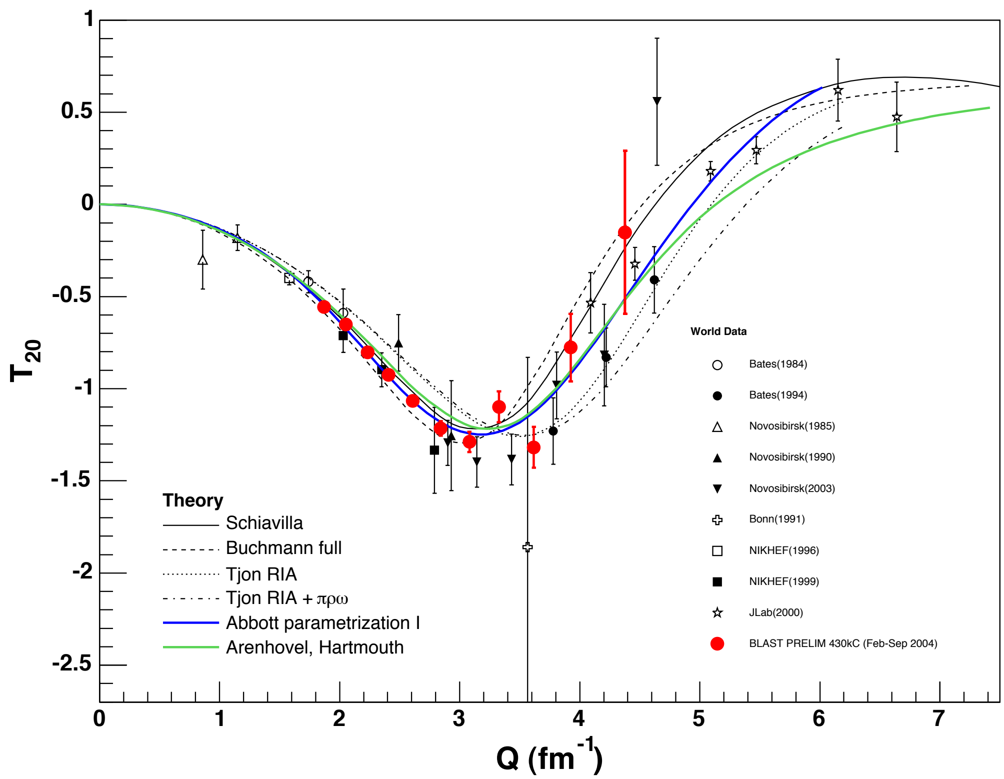

Figure 4. Preliminary results from BLAST (red circles) for T20 from *ed* elastic scattering compared to existing data and calculations from theory.

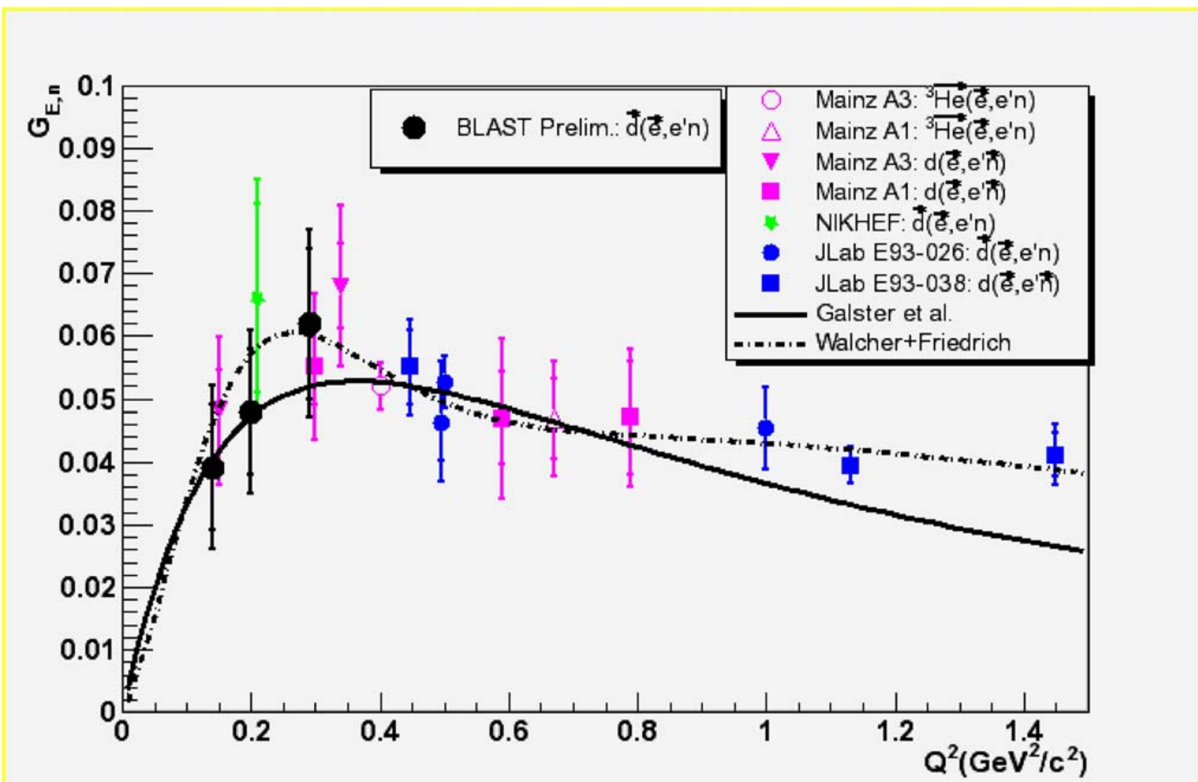

Figure 5. World data for G_E^n and preliminary BLAST data points.

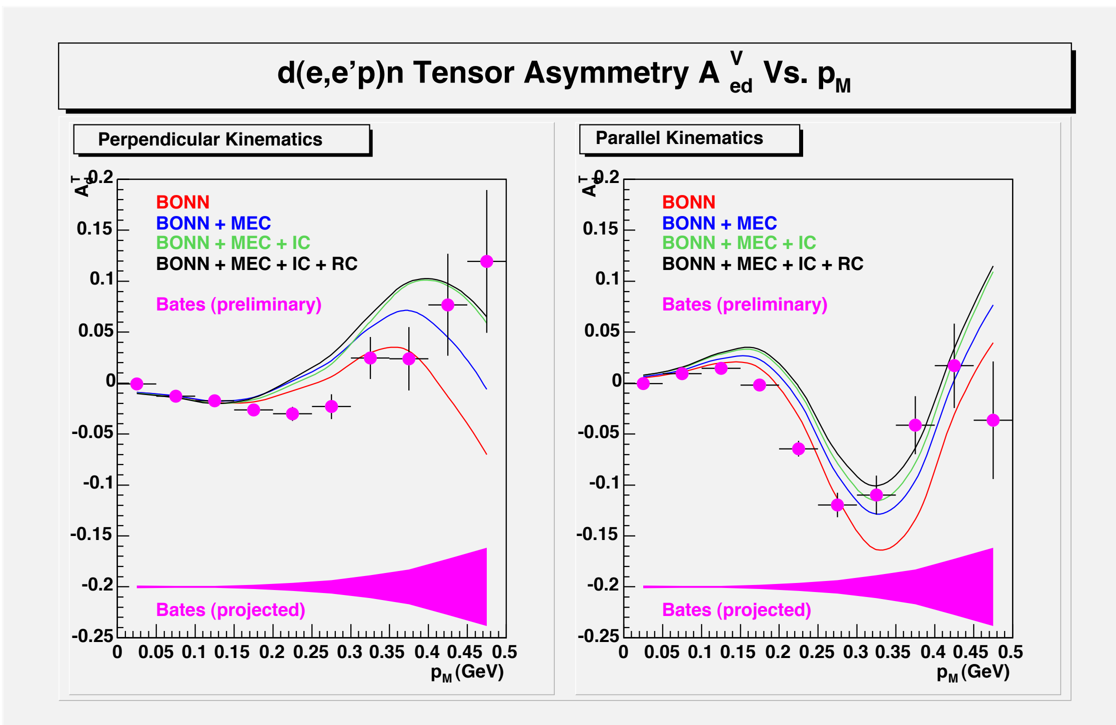

Figure 6. Preliminary results for the tensor asymmetry in quasi elastic *ep* scattering from deuterium. Curves are calculations with the Bonn potential including meson exchange, isobaric, and relativistic corrections.