Eur Phys J A (2004) **19**, s01, 283–287
Digital Object Identifier (DOI) 10.1140/epjad/s2004-03-047-3

EPJ A direct
electronic only

Status of the BLAST experiment

D.K. Hasell, for the BLAST Collaboration

Massachusetts Institute of Technology, Cambridge, MA 02139, USA

Received: 10 Oct 2003 / Accepted: 14 Nov 2003 /
Published Online: 6 Feb 2004 –

Abstract. The BLAST experiment is beginning operation at the MIT-Bates Linear Accelerator Laboratory. The experiment will study the spin dependent electro-magnetic interaction in few nucleon systems at momentum transfers between 0.1 and 1.0 GeV^2. This will provide improved measurements of the nucleon form factors, particularly G_E^n, as well as study the structure of D and ^{3}He. Other reaction channels such as pion production and inclusive scattering will also be studied. The experiment, physics goals, and current status are described briefly.

PACS. 25.30.-c – 14.20.Dh – 13.40.Gp – 21.10.Ft

1 Introduction

BLAST, Bates Large Acceptance Spectrometer Toroid, has been designed to study in a systematic manner the spin dependent, electro-magnetic interaction of few nucleon systems. Utilising a polarised electron beam with polarised targets of pure H, D, or ^{3}He BLAST will provide improved measurements of the nucleon form factors and the spin structure of D and ^{3}He. In addition, the general purpose, symmetric detector will simultaneously measure quasi-elastic, inclusive, and production channels. The strength of the BLAST program rests on the ability to measure all these quantities with a single detector while flipping the beam and target spins to reduce systematic errors.

The following sections give a brief description of the experiment, the physics motivation for BLAST, and describe the current status of the experiment with some preliminary results.

2 BLAST experiment

The BLAST experiment is situated at the MIT-Bates Linear Accelerator Laboratory[1]. The accelerator provides polarised electrons with energies up to 1 GeV. The BLAST detector, situated on the South Hall storage ring, has a symmetric design with a toroidal magnetic field and an array of detectors to provide particle tracking and identification. A variety of internal gas targets are available providing isotopically pure, polarised H, D (vector and tensor), or ^{3}He.

2.1 MIT-Bates linear accelerator

The MIT-Bates linear accelerator consists of a 500 MeV linac with a recirculator providing electron energies between 0.25 and 1 GeV. Laser induced photo-adsorption on a strained gallium-arsenide crystal is used to produce polarised electrons which are then accelerated and directed into one of two experimental halls: north or south. The initial electron beam helicity can be switched by changing the polarisation of the laser at the ion source.

BLAST is situated on the South Hall Storage Ring, SHR. Typically electron beam currents averaging 80 mA with lifetimes of ~ 25 minutes and beam polarisations of 65–70% are available. Siberian snakes are used to maintain the longitudinal beam helicity and a spin flipper can be used to reverse the helicity of the stored beam during data acquisition to reduce systematic errors. Tests with the spin flipper show $\sim 98\%$ conservation of polarisation for each spin reversal.

A Compton polarimeter[2] is situated on the SHR to measure the beam polarisation. The polarimeter uses circularly polarised laser light focused on the on-coming electron beam and measures the back-scattered photons in a CsI detector. The polarisation of the laser light can be switched in a Pockels cell and a chopper wheel allows simultaneous measurements with no laser beam for background corrections. The combined systematic and statistical error in measured beam polarisation is about 3%.

2.2 BLAST detector

The BLAST detector (see Fig. 1) is based around eight, water cooled copper coils. Each coil has 26 turns and normally carries 6730 A of current. This results in a toroidal

[1] Operated by MIT for the US Department of Energy

[2] contribution from MIT

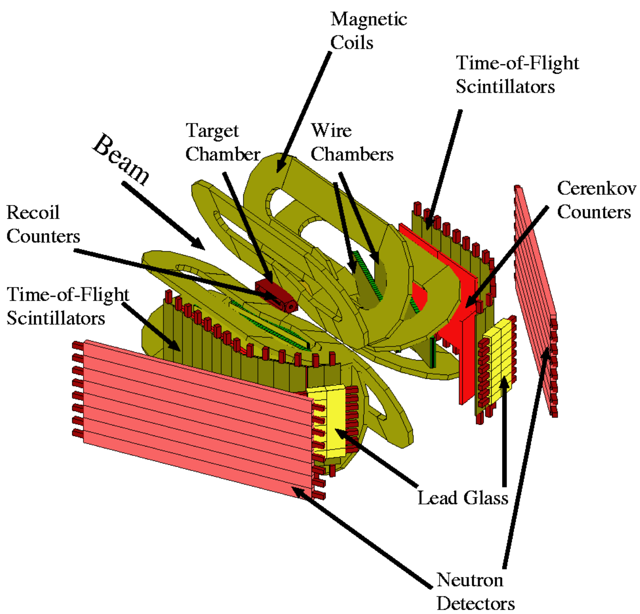

Fig. 1. Schematic, isometric view of the BLAST detector showing the main detector elements

magnetic field of up to 3500 G between the coils but less than 30 G in the region of the target. The magnetic field was mapped with a 3D Hall probe and the results agreed with calculated values to within 1%.

The detectors for BLAST are designed to detect particles scattered into the two, left and right, horizontal sectors, nominally subtending 20–80° in polar angle and ±15 ° in azimuthal angle though plans are underway to extend the polar coverage. The top sector is used for the internal target and the bottom sector has vacuum pumps. The remaining four sectors are not used at present.

The instrumented horizontal sectors (see Fig. 1) are symmetric; each consisting of wire chambers for particle tracking, Čerenkov detectors for electron identification, time of flight scintillator bars to provide a trigger and relative timing, and neutron wall to detect neutrons. In addition there are plans to install silicon strip, recoil detectors inside the target chamber to detect D and ^{3}He nuclei. The lead glass calorimeters shown in the forward region are available but not installed. Not shown in this figure are some addition neutron detectors obtained from the LADS experiment which will be used to augment the neutron detection efficiency.

In each sector there are three wire chambers[3] combined into a single gas volume to reduce multiple scattering. Each chamber has two super-layers of jet-style drift cells with 3 planes of sense wires. The super-layers are inclined ±5 ° to the vertical to allow reconstruction in three dimensions. This results in 18 layers of sense wires with which to track charged particles to determine momentum, origin in the target, and scattering angles.

[3] contribution from MIT

The Čerenkov detectors[4] use 1 cm thick Aerogel tiles inside boxes painted with a white reflective paint. PMT's (5″ diameter) at the top and bottom of the boxes detect the light produced as electrons pass through the Aerogel which has a refractive index of 1.02–1.03. There are four boxes in each sector with 6, 8, 12, and 12 PMT's for readout.

Immediately behind the Čerenkov detector are sixteen vertical bars of 1″ thick scintillator. Each bar is 8″ wide. These form the time of flight, TOF, detector[5] and are used to measure the relative timing between particles striking the TOF. Each bar is readout through PMT's at the top and bottom. The timing for each PMT is adjusted so that a relativistic particle from the target produces a signal with the same timing regardless of which TOF fires. This is necessary as the TOF also determines the timing of the trigger for the data acquisition and provides the common stop for the wire chamber TDC's.

Beyond the TOF detector is a wall of 8 horizontal scintillator bars 10 cm thick, 22.5 cm wide and 400 cm long used to detect neutrons. The neutron wall[6] bars are readout at both ends by PMT's. Additional neutron detectors are being installed using scintillator bars from the LADS experiment. These are in two varieties 15 and 20 cm thick and will double or triple the neutron detection efficiency.

The BLAST data acquisition system is based on the CODA system from TJLAB and the trigger is the same as used in Hall A of TJLAB. This allows a vary flexible system with multiple, simultaneous triggers so data can be accumulated for elastic, quasi-elastic, inclusive, and production reactions at the same time.

2.3 Internal targets

Three different internal targets[7] have been developed for the BLAST experiment: an atomic beam source (ABS), a laser driven target (LDT), and a ^{3}He target.

The ABS consists of a RF dissociator to dissociate hydrogen or deuterium molecules to atoms, a cooled nozzle for atomic beam formation, two sets of sextupoles for Stern-Gerlach selection of the desired hyperfine states and to focus them into the target cell, and RF transitions units to interchange hyperfine states as required to maximise the number of atoms with the desire polarisation. This provides polarised H and both vector and tensor D for the experiment and allows the polarisation to be changed quickly during data acquisition to minimise systematic errors. The ABS is expected to provide target densities of 5×10^{13} atoms/cm^2 with polarisations up to 80%.

The laser driven target uses circularly polarised laser light to optically pump a trace amount of K in a heated volume of dissociated H. The hydrogen atoms become polarised through spin exchange with the potassium atoms. The advantage of the LDT is the 25-30 times higher densities possible.

[4] contribution from Arizona State University
[5] contribution from University of New Hampshire
[6] contribution from Ohio University
[7] contribution from MIT

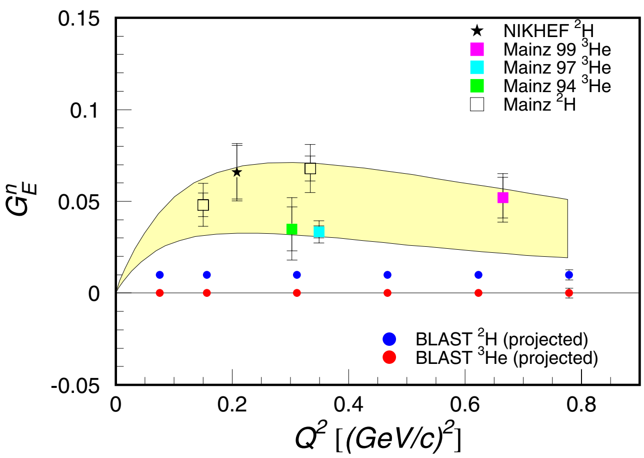

Fig. 2. The existing data for the neutron charge form factor, G_E^n, is shown. The precision and range of data expected from BLAST are shown for measurements from both D and ^{3}He targets

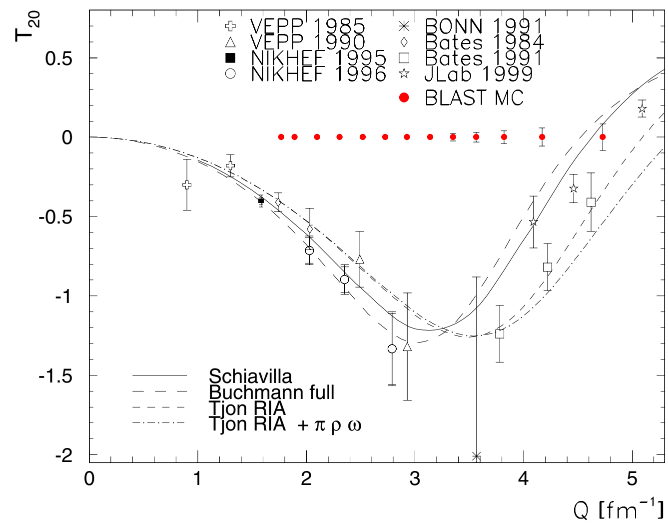

Fig. 3. The present data for T_{20} is shown together with the expected precision of the BLAST measurements

The polarised ^{3}He target provides BLAST with an effective polarised neutron target and allows a independent measurement of G_E^n from that obtained using deuterium as a target.

3 Physics goals

The design of the BLAST experiment allows many measurements to be made simultaneously. Flipping beam and target polarisations during running and the symmetric detector design reduce systematic errors. Thus BLAST will provide new and improved data for a number of elastic, quasi-elastic, inclusive, and production reactions. A few of the specific studies planned for BLAST are outlined below.

3.1 Nucleon form factors

One of the important contributions BLAST will make is in the area of nucleon form factors. 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 2 shows the existing data for G_E^n which are rather sparse and have considerable uncertainty. The expected precision and range of measurements from BLAST are indicated near the bottom of the figure. BLAST will measure G_E^n by two independent methods: using polarised D or ^{3}He as targets, which will serve as a cross check of the results. With deuterium the neutron form factor is derived from studying the quasi-elastic en scattering. Corrections must be made for the presence of the proton but BLAST can check these though the simultaneously measurement of quasi-elastic ep scattering which can be compared with the direct measurement BLAST makes using a polarised hydrogen target. The polarised ^{3}He target is effectively a polarised neutron target and again allows a measurement of quasi-elastic en scattering which can be compared with the deuterium results.

3.2 Deuteron form factors

Deuterium has three elastic form factors: G_C, G_M, and G_Q. Previous experiments, which did not enjoy polarised beams plus polarised targets, were unable to fully unfold the contributions from the three form factors or had to perform difficult double scattering experiments to measure the polarisation of the scattered deuteron. With a pure, polarised D target available in both vector and tensor polarisations BLAST can resolve all terms[1]. Existing data for T_{20} is shown in Fig. 3 together with the expected precision and extent of the BLAST measurements. The other spin asymmetries: T_{22}, T_{11} and T_{10} will also be measured and used to unfold G_C, G_M, and G_Q.

3.3 Proton radius

The proton charge and current radii are important fundamental quantities in physics. Precise determination of the proton charge radius is extremely important to the understanding of the proton structure in terms of quark and gluon degrees of freedom in QCD. It is also essential for high-precision tests of QED in the hydrogen Lamb shift measurements. The existing proton charge radius data is shown in Fig. 4 together with the expected precision of the BLAST measurement. The BLAST measurement involves measuring the elastic ep cross section at low momentum transfers and then determining the slope dG_E^p/dQ^2 as $Q^2 \to 0$ which is proportional to the proton radius.

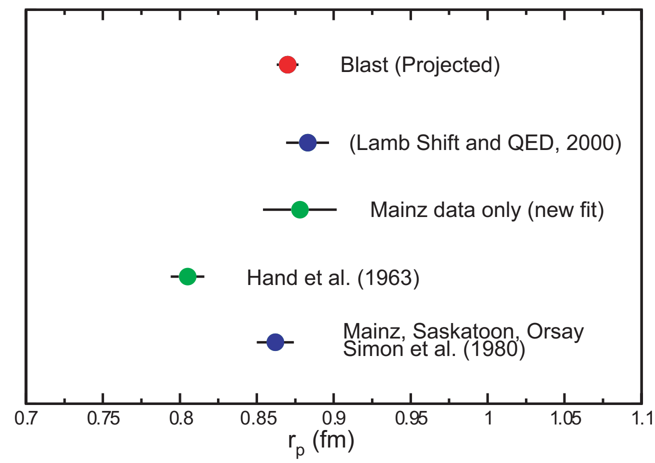

Fig. 4. This shows the existing proton radius measurements. The top point illustrates the improvement the BLAST analysis is expected to achieve

3.4 Ratio of proton form factors

There has been some recent interest[2,3,4] in the ratio of proton form factors: $\mu_p G_E^p / G_M^p$. Differing experimental results show the ratio either remaining flat and close to 1 or decreasing quite rapidly with increasing momentum transfer. The planned BLAST measurements, while quite accurate, unfortunately will be below 1 GeV^2 in momentum transfer and most likely unable to strongly support one case or the other. However, relatively simple upgrades to the South Hall Ring would permit momentum transfers up to 1.8 GeV^2 which could distinguish between the two trends.

4 Current status

The BLAST detector has been fully assembled and has been undergoing commissioning studies since May, 2003. A brief summary of the performance of main detector components is given below.

The wire chambers showed clear tracks but initially suffered from a space charge effect which caused excessive noise. This was solved by changing the gas mixture to a 70:30 mixture of He:iso-butane and adding a trace amount of water vapour to the gas system. The chambers now run very quietly as can be seen in Fig. 5 which shows the wire chamber hits along the two tracks and no random or noise hits elsewhere in the chamber. Another significant factor in the chamber operation was found to be a careful tune of the storage ring beam. Four scintillators placed downstream of the target are used to optimise the beam transport through the target cell. Determining the calibration parameters for the wire chamber is on-going. Currently the average resolution for individual wires is better than 200 μm but overall track reconstruction shows a momentum resolution of $\sim$5%. Improved calibration and reconstruction including energy loss corrections and kinematic fitting should improve the momentum resolution to better than 2%.

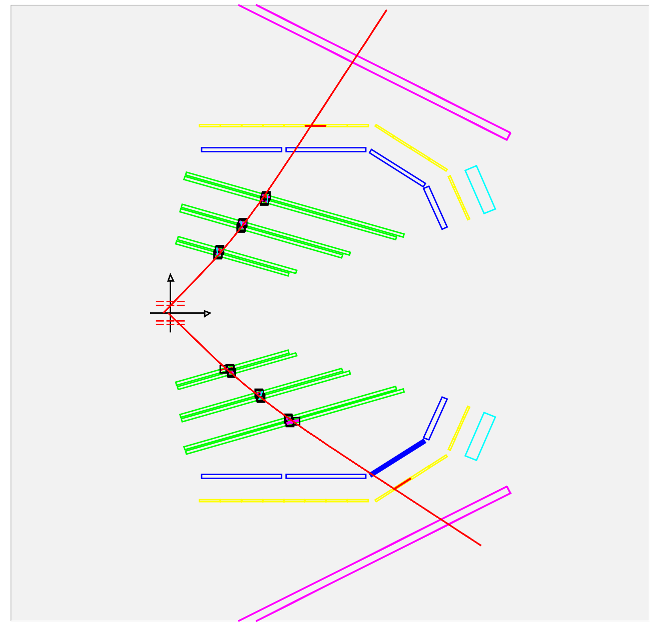

Fig. 5. A typical elastic ep scattering event with reconstructed tracks. The lower track shows an electron which fires the Čerenkov detector and TOF while the top track is the proton with only a recorded hit in the TOF

The PMT's for the Čerenkov detectors initially showed a 50% decrease in efficiency when the toroidal magnetic field was on. The 5″ PMT's used are sensitive to stray fields of only 0.5 G and additional shielding was required to eliminate such fields. Now electron identification efficiency is 85–90% and can be used to significantly clean-up event selection.

The PMT's on the TOF detector also changed slightly when the toroid was on so an extra layer of μmetal was necessary. The meantime of the TOF signals were timed so the trigger (and hence COMMON STOP for the wire

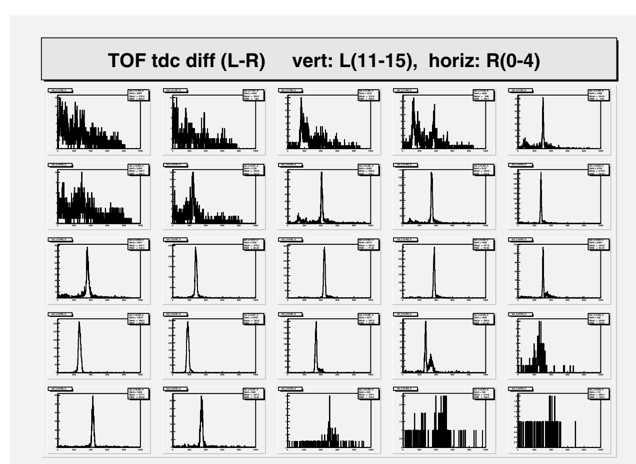

Fig. 6. TDC distributions for the back angle TOF's in the *left sector* in coincidence with forward angle TOF's of the *right sector*. The strong peak seen in the diagonal elements correspond to elastic *ep* scattering

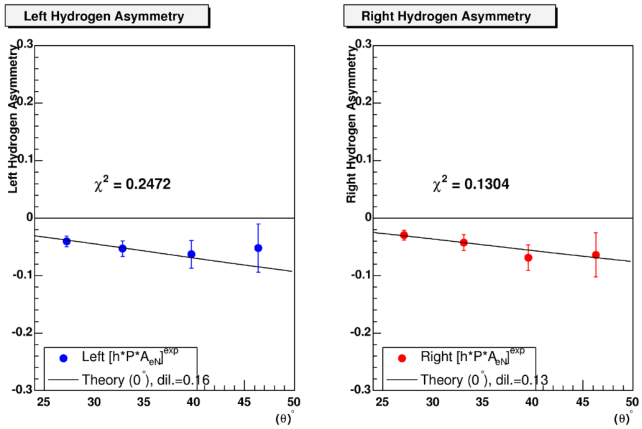

Fig. 7. Asymmetry measured in *left* and *right sectors* for *ep* elastic scattering. The *solid lines* indicate the expected asymmetries assuming a product of beam and target polarisations of 0.13–0.16

chambers) is independent of which TOF is struck. Using just the relative timing of the TOF detector it is possible to select very clean elastic scattering events as illustrated in Fig. 6 which shows a strong, correlated timing peak between the left and right sector TOF's corresponding to elastic *ep* scattering. A timing resolution of better than 600 ps has been achieved for the TOF detector.

The atomic beam source, ABS, was the first target used at BLAST and several initial problems had to be overcome. Firstly, the toroidal magnetic field caused a precession of the atomic spin during transport which decreased the intensity focused into the target cell. Adding iron shielding solved this problem. However, the combination of toroidal field and additional iron caused hysteresis affects when the magnetic fields of the ABS transition units were changed. Since the controllers monitored current rather than produced field the wrong transition field was often set which reduced he polarisation. Studies with the ion polarimeter to measure atomic fraction and careful tuning of the transitions for a fixed state did enable polarised running but without the rapid spin reversal of the target. Figure 7 shows the measured asymmetries in the left and right sectors as a function of the scattering angle. With an average beam polarisation of $\sim 65\%$ the measured asymmetry is consistent with a target polarisation of $\sim 22\%$.

The ABS is currently removed to improve the magnetic shielding, install Hall probes to monitor the field of the transition units, improve the pumping, and to upgrade the RF control system. These improvements should enable the ABS to be operated as intended.

5 Conclusion

The BLAST experiment expects to begin production running in the Fall, 2003. Problems identified during the commissioning studies have been solved. With the polarised electron beam from the MIT-Bates linear accelerator, high polarisation, isotopically pure internals targets of H, D, or ^{3}He, and a symmetric, general purpose detector system BLAST will make significant measurements of a number of important physics quantities.

References

1. T.W. Donnelly and A.S. Raskin: Ann. Phys. **169**, 247 (1986)
2. M.K. Jones et al.: Phys. Rev. Lett. **84**, 1398 (2000)
3. O. Gayou et al.: Phys. Rev. C **64**, 038202 (2001)
4. O. Gayou et al.: Phys. Rev. Lett. **88**, 092301 (2002)