Recent Results from BLAST

**Bates Large Acceptance Spectrometer Toroid**

- Symmetric, large acceptance, general purpose detector
- Polarized electron beam (850 MeV, 65% polarization)
- Highly polarized, internal, gas targets of H and D
- Systematic study of the spin-dependent, electro-magnetic interaction in few nucleon systems
  - Nucleon form factors
  - Deuteron form factors
  - Study few body effects, pion production, …
MIT-BATES Linear Accelerator Laboratory

500 MeV Linac + Recirculator

Electrons up to 1 GeV electrons

70% polarization typical

South Hall Storage Ring

- 175 mA injected, ~25 minute lifetime
- Siberian snake, spin flipper
- 65% polarization in ring typical

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Compton Polarimeter

- Laser strikes oncoming electron beam
- Backscattered photons detected in CsI
- Laser helicity flipped in Pockels cell
- Chopper wheel allows simultaneous measure of background
- Asymmetry gives online measure of beam polarization
Polarized, Internal, Gas Target

Atomic Beam Source
- Isotopically pure H or D
  - Vector polarized H
  - Vector and Tensor polarized D
- Holding field 32 deg to left
- Parallel/perpendicular kinematics
- Rapidly change polarization
  - Change every 5 minutes
  - Reduce systematic errors

Target thickness for D (60 cm cell)
- $6 \times 10^{13}$ Atoms/cm²

Typical polarizations for D
- $P_Z \approx 72\%$
- $P_{ZZ} \approx 68\%$
BLAST Detector

Toroidal magnet
- $B_{\text{MAX}} = 3.8$ kG

Drift chambers
- 3 chambers/sector
- 2 superlayers/chamber (±5°)
- 3 sense layers/superlayer
- 18 tracking layers/sector
- 954 sense wires

Aerogel Cerenkov detectors
- 1 cm thick
- Electron identification

Time of Flight scintillators
- 16 vertical bars 5 cm thick
- Trigger and relative timing

Neutron detectors
- 10 cm thick left sector
- 25-30 cm thick right sector

2 level Trigger system
- Several reaction channels
- Simultaneous measurements
TOF Coincidence for $ep$ Elastic Scattering

$\theta_p = 70^\circ$

$\theta_p = 30^\circ$

$\theta_e = 20^\circ$

$\theta_e = 80^\circ$

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25/10/04
Track Reconstruction

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<table>
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<td>$\sigma_p$</td>
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<td>$\sigma_\theta$</td>
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<td>$\sigma_\phi$</td>
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<tr>
<td>$\sigma_z$</td>
<td>1cm</td>
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$\Delta p_e = 22\text{ MeV}$

$\Delta \theta = 0.5^\circ$

$\Delta \phi = 0.6^\circ$

$\Delta z = 1\text{ cm}$
BLAST Data

H run 1, December 2003
- reversed BLAST field – electrons out-bending
- 20 kC beam (3.4 pb\(^{-1}\)) \(P_z = 45\%\) 480k elastic events

H run 2, April 2004
- nominal BLAST field – electrons in-bending
- 57 kC beam (9.6 pb\(^{-1}\)) \(P_z = 40\%\) 950k elastic events

D run, May – October 2004
- 450 kC beam (169 pb\(^{-1}\)) \(P_z = 72\%\), \(P_{zz} = 68\%\)

H run 3, November 2004
- \(~250\) kC (\(~60\) pb\(^{-1}\))

Following results preliminary
**ep Elastic Scattering - $\mu G_E^p/G_M^p$**

**Ratio of Proton Form Factors**

**Rosenbluth separation**

**Unpolarized scattering**

\[
S = A(Q^2) + B(Q^2) \tan^2 \frac{\theta_e}{2}
\]

\[
A(Q^2) = \frac{G_E^p + G_M^p}{1 + \tau}
\]

\[
B(Q^2) = 2\tau G_M^p
\]

**Polarization transfer**

**Polarized electron beam**

\[
G_E^p = -\frac{P_t}{P_t} \frac{E + E'}{2M_p} \tan \frac{\theta_e}{2}
\]
\[ \mu G^p_E/G^p_M \text{ from Ratio of Asymmetries} \]

Polarized beam and target \( \Rightarrow \) can use asymmetries

\[ A_{exp} = P_b P_t \frac{2\tau v_{LT'} \cos \theta^* G^p_M}{(1+\tau)v_L G^p_E} + \frac{2\sqrt{2\tau(1+\tau)v_{LT'}} \sin \theta^* \cos \phi^* G^p_M G^p_E}{(1+\tau)v_L G^p_E + 2\tau v_T G^p_M} \]

Target spin angle 32° into sector

- **Electron into left sector**
  - \( q \) roughly perpendicular to spin, \( \theta^* \sim 90^\circ \)

- **Electron into right sector**
  - \( q \) roughly parallel to spin, \( \theta^* \sim 0^\circ \)

Symmetric detector \( \Rightarrow \) form ratio of L/R asymmetries

- **Denominator cancels**

\[ R_A = \frac{A_L}{A_R} = \frac{x^*_L - x^*_L \cdot G^p_E/G^p_M}{x^*_R - x^*_R \cdot G^p_E/G^p_M} \]
Preliminary Super-Ratio Results

Preliminary data

5x more to come
to 0.8 (GeV/c)^2

Low Q^2
- independent measurement
- normalization
- proton radius
- information on pion cloud
Deuteron form factors $G_C$, $G_M$, and $G_Q$
- $G_Q$ arising from D state contributions $\Rightarrow$ tensor force

Rosenbluth separation insufficient

$$A(Q^2) = G_C^2(Q^2) + \frac{8}{9} \eta^2 G_Q^2(Q^2) + \frac{2}{3} \eta G_M^2(Q^2)$$

$$B(Q^2) = \frac{4}{3} \eta (1 + \eta) G_M^2(Q^2)$$

Need extra measurement $\Rightarrow$ tensor asymmetry

$$A = \sqrt{2} \frac{N^+ - N^-}{N^- P_{zz}^+ - N^+ P_{zz}^-}$$

$$A = \frac{3 \cos^2 \theta_d^* - 1}{2} T_{20} - \sqrt{\frac{3}{2}} \sin 2\theta_d^* \cos \phi_d^* T_{21} + \sqrt{\frac{3}{2}} \sin^2 \theta_d^* \cos \phi_d^* T_{22}$$

$$T_{20} = -\frac{1}{\sqrt{2} S} \left[ \frac{8}{3} \eta G_C G_Q + \frac{8}{9} \eta^2 G_Q^2 + \frac{1}{3} \eta [1 + 2(1 + \eta) \tan^2 \frac{\theta_2}{2}] G_M^2 \right]$$
**eD Elastic Event Selection**

**Event selection**
- basic timing cuts
- 2 oppositely charged tracks + coplanarity
- D mass from momenta and energy from timing

**Background**
- cell walls, positrons from beam halo, misidentified protons
- study with empty and H runs
80% of available data included in this analysis (280 K)

Tensor polarization of target obtained by normalizing at low $Q^2$

Systematics still need to be checked

Consistency checks with $T_{11}$ and $T_{10}$

Unfold deuteron form factors

D state contribution
Deuterium readily breaks up into two nucleons
- \( e + d \rightarrow e' + p + n \)
- electro-disintegration

d(e,e'N)N cross section can be written as:

\[
S(h,P_z,P_{zz}) = S_0 \left( 1 + P_z A_d^V + P_{zz} A_d^T + h \left( A_e + P_z A_{ed}^V + P_{zz} A_{ed}^T \right) \right)
\]

In Born approximation

\[
A_e = A_d^V = A_{ed}^T = 0
\]

\[
S = S_0 (1 + P_{zz} A_d^T + h P_z A_{ed}^V)
\]

\(~G_E G_M = 0\) for S state
$e'p$ Vector Asymmetry Results

Analysis of 200kC of 450kC collected data
Vector polarization from fitting asymmetry below $p_M = 0.15\text{GeV}$
Vector asymmetry sensitive to $G_E^p G_M^p$ see subnuclear effects

\[ d(e,e'p)n \text{ Beam-Vector Asymmetry } A_e^V \text{ Vs. } p_M \]
Tensor polarization from independent $T_{20}$ fit
Sensitive to D state contributions
**e’n Event Selection, Missing Mass/Momenta**

- timing cuts, only 1 charged track, hit in neutron detector
- time resolution of ~5 ns
- Neutron momentum resolution: ~5%
- require missing mass to be \( m_p \)

- High signal to noise ratio
- 140k total neutrons after cuts
- <2% empty target contribution
- ~10% background from hydrogen
Preliminary $G_n^E$ World Plot

Preliminary result

Only 60% of data, final data should reach 0.5

Use Arenhovel’s calculations for $G_n^M$ and contribution of $G_n^E$

Need to combine with other BLAST measurements for global fit

Provide low $Q^2$ data
- Check bump
- Pion cloud

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BLAST Results Still to Come

$G_M^n$ from inclusive electron scattering from D

$T_{10}$ and $T_{11}$ from $eD$ elastic scattering

Pion production

2005 polarised $^3$He target
- effective polarised n target
- cross check for $G_E^n$ results
- elastic $^3$He
- $N \rightarrow \Delta$