Parity Violating elastic e-N scattering

polarized electrons, unpolarized target

\[ A = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} = \left[ -\frac{G_F Q^2}{4\pi\alpha\sqrt{2}} \right] \frac{A_E + A_M + A_A}{2\sigma_{unpol}} \]

\[ A_E = \varepsilon(\theta) G^Z_E G^\gamma_E \]
\[ A_M = \tau G^Z_M G^\gamma_M \]
\[ A_A = -(1 - 4\sin^2\theta_W)\varepsilon' G^e_A G^\gamma_M \]

Neutral Weak ffs contain explicit contributions from strange sea

\[ G_{E,M}^Z(Q^2) = (1 - 4\sin^2\theta_W)(1 + R_A^p)G_{E,M}^p - (1 + R_A^n)G_{E,M}^n - G_{E,M}^s \]
\[ G_A^e(Q^2) = -G_A^Z + (\eta F_A^\gamma + R^e) + \Delta s \]
The G0 experiment at JLAB

- Forward and backward angle PV e-p elastic and e-d (quasielastic) in Hall C
- Superconducting toroidal magnet
- Scattered particles detected in segmented scintillator arrays in spectrometer focal plane
- **Forward angle**: measure recoiling protons identified via time-of-flight
- **Backward angle**: measure scattered electrons identified via front/back scint. matrix
- **forward angle run completed**
- **backward angle run began March 2006**

\[ G_E^s, G_M^s \text{ and } G_A^e \text{ separated over range } Q^2 \sim 0.1 - 1.0 \text{ (GeV/c)}^2 \]
G0 Forward Angle Results

Examining full data set, probability that $G_E^s + \eta G_M^s \neq 0$ is 89%

D.S. Armstrong, et al., PRL 95, 092001 (2005)
World Data at $Q^2 = 0.1 \text{ GeV}^2$
(pre-HAPPEX ’05)

- G0 results (extrapolated to $Q^2=0.1$ GeV$^2$) combined with world data:
  
  \[
  G_E^s = -0.103 \pm 0.28 \\
  G_M^s = 0.62 \pm 0.31
  \]

- Much excitement caused by $2\sigma$ deviation of $G_M^s$ from zero
World Data at $Q^2=0.1$ GeV$^2$

“Rosenbluth Plot”

- Post-HAPPEX '05
  
  $G_E^s = 0.006 \pm 0.016$
  
  $G_M^s = 0.28 \pm 0.20$

- New HAPPEX results yield smaller $G_M^s$

- Even with this shift in the central value, world data still remarkably consistent

$$\eta = \frac{\tau G_M^p}{\varepsilon G_E^p}$$

Thanks to Kent Paschke for plot
G0 Backangle

- 2 measurements scheduled in 2006-2007
  - PAC 28 recommended common strategy with HAPPEX III (high precision forward angle measurement) -> $Q^2 = 0.6 \text{ GeV}^2$
  - $Q^2 = 0.23 \text{ GeV}^2$ -> common $Q^2$ with Mainz PVA4 forward measurement

<table>
<thead>
<tr>
<th>$E_e$ (MeV)</th>
<th>$Q^2$ (GeV$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>362</td>
<td>0.23</td>
</tr>
<tr>
<td>686</td>
<td>0.62</td>
</tr>
</tbody>
</table>

- Small $Q^2$ acceptance requires 2 different beam energies for 2 $Q^2$'s
- Measurements on LH2 and LD2 targets (M, A separation)
- Running (with a couple breaks) from mid-March 2006 to February 2007
  - 687 MeV: March-April, September-December
  - 362 MeV: July-September, January-February 2007
G0 in Hall C: The key elements

- Superconducting Magnet (SMS)
- Target service module
- G0 beam monitoring
- Detectors (Ferris wheel) FPD
- Spokesman
- Detectors (Mini-Ferris wheel) CED+Cherenkov
G0 Backangle Configuration

- **Particle detection and identification**
  - Superconducting magnet turned around to detect electrons at $\theta_e \sim 110^\circ$
  - Cryostat Exit Detectors (CED) to separate elastic and inelastic electrons

- **Cerenkov detector**
  - $\pi/e$ separation (both are recorded)
  - 5 cm aerogel, $n= 1.03$ (OK for $p_\pi < 380$ MeV/c),
  - 90% efficient for e- and $\pi$ rejection factor $\approx 100$
  - From cosmic muons and test beam: 5-8 p.e.
  - Special design for Magnetic shielding (SMS fringe field)
Polarized Beam During First Backangle Run Period

- **Polarized source**
  - 85% polarization has been reached routinely using superlattice GaAs cathodes
  - New Fiber laser for Hall C (adjustable pulse repetition rate)
    - Allows flexible time structure (1-2h for setting) : 32 ns used for Cerenkov study
    - 780 nm is at polarization peak (P ~ 85%) for superlattice GaAs

- **Beam properties**
  - Hall C instrumentation OK
  - 60 μA of low energy beam
    - New optics, beam dump and halo handled
  - Parity quality beam properties
    - Adiabatic damping, PITA, RWHP, IA
    - 35 h IN and 42 h OUT at 60 μA (LH2)
    - Room for improvement (position feedback)
    - Halo within a 6 mm diameter was determined to be < 0.3 x 10^{-6} (spec : 10^{-6} )

### Beam Param. | Achieved in G^0 (IN-OUT) | Specs
--- | --- | ---
Charge asym. | -0.4 ± 0.24 ppm | 2 ppm
X-Y position diff. | 20-24 ± 5 nm | 40 nm
X-Y angle diff. | -2 to -4 ± 2 nrad | 4 nrad
Energy diff. | 2 ± 4 eV | 30 eV
31 MHz Beam for Cerenkov Efficiency Studies

- At these low energies, can separate electrons and pions via time-of-flight
- Use FPDs to measure difference between beam pulse arrival time at target and particle arrival at FPD

\[ t_{FPD} - t_{target} \]
Polarimetry and target

- Møller polarimeter in Hall C
  - Design min. beam energy = 1 GeV
  - Need to move quadrupole closer to target
  - Tune difficult due to 3 T solenoid
  - Finally successful at 686 MeV
  - 1 \(\mu\)m foil = \(-86.36 \pm 0.36\)% (stat)
  - 4 \(\mu\)m foil = \(-85.94 \pm 0.33\)% (stat)
  - Systematic error \(\approx 2\) %, expected to be reduced

- Target and Lumi detectors
  - LH2 and LD2 target
    - (“Flyswatter” and gas target for cell contribution)
  - Target boiling test with Lumi detectors
    - Intensity up to 60 mA
    - Very flat behavior (rates/beam current)
    - Ratio LD2:LH2:12C are the ones expected
Particle ID: CED-FPD Matrix
(rates in Hz/μA per octant)

<table>
<thead>
<tr>
<th>60 μA, LH₂</th>
<th>10 μA, LD₂</th>
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</table>

Electrons

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<th>60</th>
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Pions

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<th>1600</th>
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<tbody>
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<td>1600</td>
</tr>
<tr>
<td>1</td>
<td>1200</td>
<td>1600</td>
</tr>
</tbody>
</table>
Random Coincidences, Lost Events

Randoms $\sim I^2$

Lost events (dead time, multi-hit) $\sim I$

Fraction of coincidences lost (%)

LH$_2$

60 $\mu$A

LD$_2$

10 $\mu$A
Electron Asymmetries from LH2

Matrix Space Cuts

Insertable Half-wave Plate State

IN | OUT

Elastic

Super Elastic

Background
Electron Asymmetries from LH2

\[ \langle A_{\text{raw}} \rangle^{\text{IN}} + \langle A_{\text{raw}} \rangle^{\text{OUT}} = -9.80 \pm 11.08 \]

\[ \langle A_{\text{raw}} \rangle^{\text{IN}} = 28.02 \pm 9.30 \]

\[ \langle A_{\text{raw}} \rangle^{\text{OUT}} = -37.81 \pm 6.01 \]

(very) preliminary and blinded

\[ \langle A_{\text{raw}} \rangle^{\text{IN}} + \langle A_{\text{raw}} \rangle^{\text{OUT}} = -0.46 \pm 15.68 \]

\[ \langle A_{\text{raw}} \rangle^{\text{IN}} = 30.518 \pm 13.18 \]

\[ \langle A_{\text{raw}} \rangle^{\text{OUT}} = -30.98 \pm 8.50 \]

\[ \langle A_{\text{raw}} \rangle^{\text{IN}} = 19.84 \pm 14.63 \]

\[ \langle A_{\text{raw}} \rangle^{\text{OUT}} = -12.30 \pm 9.47 \]
Pion Asymmetries from LH2

**Elastic Cut Pions**

\[
\langle A_{\text{raw}} \rangle^{\text{IN}} + \langle A_{\text{raw}} \rangle^{\text{OUT}} = 3.06 \pm 13.26
\]

\[
\langle A_{\text{raw}} \rangle^{\text{IN}} = 13.15 \pm 11.11
\]

\[
\langle A_{\text{raw}} \rangle^{\text{OUT}} = -10.10 \pm 7.23
\]

**Inelastic Cut Pions**

\[
\langle A_{\text{raw}} \rangle^{\text{IN}} + \langle A_{\text{raw}} \rangle^{\text{OUT}} = 3.09 \pm 13.35
\]

\[
\langle A_{\text{raw}} \rangle^{\text{IN}} = -8.58 \pm 11.20
\]

\[
\langle A_{\text{raw}} \rangle^{\text{OUT}} = 11.67 \pm 7.36
\]

**Background Cut Pions**

\[
\langle A_{\text{raw}} \rangle^{\text{IN}} + \langle A_{\text{raw}} \rangle^{\text{OUT}} = 24.69 \pm 16.35
\]

\[
\langle A_{\text{raw}} \rangle^{\text{IN}} = 32.65 \pm 13.69
\]

\[
\langle A_{\text{raw}} \rangle^{\text{OUT}} = -7.97 \pm 8.94
\]
Summary of 1st 687 MeV Run

- Successfully commissioned new detectors and electronics
- Extensive shielding helped keep detector rates and anode currents under control
- Polarimeter commissioning took longer than expected, but eventually successful -> beam energy ~ 300 MeV below design limit
- Beam delivery very good
  - Beam within parity quality specs
  - Early issues with beam halo were resolved
- Took production data on LH2 at 60 $\mu$A
- Some issues remain to be addressed for LD2
  - High singles rates and anode currents for Cerenkov detectors
  - High rates singles in FPDs and CEDs lead to a large number of random coincidences
Test Run at 362 MeV

- This summer, we will run at 362 MeV – CEBAF will become a “half-pass” machine!
- Beam delivery extremely challenging at these low energies – even the Earth’s magnetic field cannot be ignored
- 3 day test run in mid-May was very successful
  - Parity quality beam delivered
  - Low halo right from the start
  - G0 was able to do some tests with LD2 to address rate issues
    - Nice solution seems to have been found for large FPD-CED random coincidence rates
    - Test data seems to point to thermal neutrons as the background source in the Cerenkov detectors (capture on Boron in PMT glass?) but this is still under investigation
G0 Summary

- **G0 Forward angle**
  - Strange quark contribution non-zero at 89% confidence level
  - Nicely consistent with emerging picture at $Q^2=0.1$ GeV$^2$
  - Gave some clues about where to look next (HAPPEX-III)

- **G0 Backward angle**
  - Provide clean separation of $G_E^s$, $G_M^s$, and $G_A$ at $Q^2=0.23$ and 0.6 GeV$^2$
  - First run at 687 MeV just completed – got a lot accomplished
  - Will keep running throughout 2006 and into 2007 at 362 MeV and 687 MeV
New Fiber-Based Laser Used During $G^0$ Backangle

- Uses 1560 nm seed laser and amplifier commonly used in the telecommunications industry
- Electrical gain-switching avoids phase lock problems experienced with earlier optically modelocked systems
- Second harmonic generation device yields some 780 nm light from the 1560 nm light
- 780 nm is at polarization peak ($P \sim 85\%$) for superlattice GaAs
362 MeV Test Run – “online” data

Tests performed at 362 MeV (but of interest for 686 MeV)

- Random/loss reduction in FPD
  - Octants 4 and 5 modified and factor 5-10 reduction indeed observed (left)
- LD2 target
  - Pion/electron ratio decreased by a factor of 10 (right)