Parity-Violating Electron Scattering on Hydrogen and Deuterium at Backward Angles: G0 Experiment

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For the G0 Collaboration

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Outline

• Parity violation in electron scattering
• Vector Strange Form Factors: $G_E^s$ and $G_M^s$
• Experimental Effort

• Results from G0 at backward angles:
  - Separated form factors at $Q^2 = 0.23, 0.63 \text{ (GeV/c)}^2$
  - Other physics results
• Implications & Conclusions

“There is no excellent beauty that hath not some strangeness in the proportion"
Francis Bacon 1561-1626
Goal: Determine the contributions of the strange quark sea (s\bar{s}) to the charge and magnetization distributions in the nucleon:

Vector “strange form factors”: $G_E^s$ and $G_M^s$

Nucleon in QCD

- $P = uu\bar{d} + u\bar{u} + \bar{u}d + s\bar{s} + g + ...$
- « sea »
- $s$ quark: clean candidate to study the sea

How much do virtual $s\bar{s}$ pairs contribute to the structure of the nucleon?
- Momentum: 4% (DIS)
- Spin: 0 to -10% (polarized DIS)
- Mass: 0 to 30% ($\pi N$-sigma term)
  (significant uncertainties on the latter two)

Also: OZI violations in $p\bar{p} \rightarrow \phi\gamma$
Parity Violating Electron Scattering
Weak NC Amplitudes

Interference with EM amplitude makes Neutral Current (NC) amplitude accessible

\[ \sigma \sim |M^{EM}|^2 + |M^{NC}|^2 + 2 \text{Re}(M^{EM*})M^{NC} \]

\[ A_{PV} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} \sim \left| \frac{M^{NC}_{PV}}{M^{EM}} \right| \sim \frac{Q^2}{(M_Z)^2} \]

Small (~10^{-6}) cross section asymmetry isolates weak interaction
Nucleon Form Factors

Adopt Sachs FF:

\[ G_E^\gamma = F_1^\gamma + \tau F_2^\gamma \quad G_M^\gamma = F_1^\gamma + F_2^\gamma \]

(Roughly: Fourier transforms of charge and magnetization)

NC and EM probe same hadronic flavor structure, with different couplings:

\[ G_{E/M}^{Z} = \left(1 - \frac{8}{3} \sin^2 \theta_W\right) G_{E/M}^{u} - \left(1 - \frac{4}{3} \sin^2 \theta_W\right) G_{E/M}^{d} - \left(1 - \frac{4}{3} \sin^2 \theta_W\right) G_{E/M}^{s} \]

\( G_{E/M}^{Z} \) provide an important benchmark for testing non-perturbative QCD structure of the nucleon
Charge Symmetry

One expects the neutron to be an isospin rotation of the proton*:

\[ G_{E/M}^{p,u} = G_{E/M}^{n,d}, \quad G_{E/M}^{p,d} = G_{E/M}^{n,u}, \quad G_{E/M}^{p,s} = G_{E/M}^{n,s} \]

Isolating individual form factors:

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

\[ \sim \text{few parts per million} \]

For a proton:

\[ A_E = \epsilon G_E^p G_E^Z, \quad A_M = \tau G_M^p G_M^Z, \quad A_A = -\left(1 - 4\sin^2 \theta_W\right) \epsilon G_M^p G_A^e \]

\[ G_{E,M}^Z = (1-4\sin^2 \theta_W)(1+R_V^p)G_{E,M}^p - (1+R_V^n)G_{E,M}^n - G_{E,M}^s \]

Forward angle \quad Backward angle

\[ G_A^e = -\tau_3 (1+R_A^{T=1}) G_A + \sqrt{3} R_A^{T=0} G_A^8 + \Delta s \]

For $^4\text{He}$: $G_E^s$ alone

For deuteron: enhanced $G_A^e$ sensitivity

\[ A_d = \frac{\sigma_p A_p + \sigma_n A_n}{\sigma_d} \]
Theoretical Approaches to Strange Form Factors

Models - a non-exhaustive list:

kaon loops, vector dominance, Skyrme model, chiral quark model, dispersion relations, NJL model, quark-meson coupling model, chiral bag model, HBChPT, chiral hyperbag, QCD equalities, ...

- no consensus on magnitudes or even signs of $G_E^s$ and $G_M^s$!

Only model-independent statement: $G_E^s(Q^2=0) = 0$

* a challenging problem in non-perturbative QCD

What about QCD on the lattice?
- Dong, Liu, Williams  PRD 58(1998)074504

*situation is unsettled*
Strangeness Models

10% of $\mu_N^{T=1}$

Snapshot as/of 2004

note: caveats...
The Axial Current Contribution

- Recall:
  \[ A_{PV}^A \propto \frac{A_E + A_M + A_A}{2\sigma_{unp}} \]

  \[ A_E = \varepsilon(\theta) G_E^\gamma G_E^Z, \quad A_M = \tau G_M^\gamma G_M^Z \]

  \[ A_A = -\left(1 - 4\sin^2 \theta_W\right) \varepsilon'(\theta) G_M^\gamma G_A^e \]

  \[ G_A^e = -\tau_3 (1 + R_A^{T=1}) G_A + \sqrt{3} R_A^{T=0} G_A^8 + \Delta s \]

- Effective axial form factor: \( G_A^e(Q^2) \)
- related to form factor measured in neutrino scattering
- also contains “anapole” form factor
- determine isovector piece by combining proton and neutron (deuteron) measurements
## Parity-Violating Electron Scattering Program

<table>
<thead>
<tr>
<th>Expt/Lab</th>
<th>Target/ Angle</th>
<th>Q² (GeV²)</th>
<th>$\mathcal{A}_{\text{phys}}$ (ppm)</th>
<th>Sensitivity</th>
<th>Status</th>
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<tbody>
<tr>
<td><strong>SAMPLE/Bates</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>SAMPLE I</td>
<td>LH₂/145</td>
<td>0.1</td>
<td>-6</td>
<td>$\mu_s + 0.4G_A$</td>
<td>2000</td>
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<td>-4</td>
<td>$\mu_s + 3G_A$</td>
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<td>HAPPEx</td>
<td>LH₂/12.5</td>
<td>0.47</td>
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<td>$G_E + 0.39G_M$</td>
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<td>LH₂/6</td>
<td>0.11</td>
<td>-1.6</td>
<td>$G_E + 0.1G_M$</td>
<td>2006, 2007</td>
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<tr>
<td>HAPPEx He</td>
<td>$^4$He/6</td>
<td>0.11</td>
<td>+6</td>
<td>$G_E$</td>
<td>2006, 2007</td>
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<td>HAPPEx</td>
<td>LH₂/14</td>
<td>0.63</td>
<td>-24</td>
<td>$G_E + 0.5G_M$</td>
<td>(2009)</td>
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<td><strong>A4/Mainz</strong></td>
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<td></td>
<td>LH₂/35</td>
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<td>-5</td>
<td>$G_E + 0.2G_M$</td>
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<td>$G_E + 0.1G_M$</td>
<td>2005</td>
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<tr>
<td></td>
<td>LH₂/145</td>
<td>0.23</td>
<td>-17</td>
<td>$G_E + \eta G_M + \eta' G_A$</td>
<td>2009</td>
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<tr>
<td></td>
<td>LH₂/35</td>
<td>0.63</td>
<td>-28</td>
<td>$G_E + 0.64G_M$</td>
<td>(2009)</td>
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<td><strong>G0/JLab</strong></td>
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<tr>
<td>Forward</td>
<td>LH₂/35</td>
<td>0.1 to 1</td>
<td>-1 to -40</td>
<td>$G_E + \eta G_M$</td>
<td>2005</td>
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<tr>
<td>Backward</td>
<td>LH₂/LD₂/110</td>
<td>0.23, 0.63</td>
<td>-12 to -45</td>
<td>$G_E + \eta G_M + \eta' G_A$</td>
<td>2009</td>
</tr>
</tbody>
</table>
Summary of data at $Q^2 = 0.1 \text{ GeV}^2$

Solid ellipse:
K. Paschke, private comm, [same as J. Liu, et al PRC 76, 025202 (2007)], uses theoretical constraints on the axial form factor

Dashed ellipse:
R. Young, et al. PRL 97 (2006) 102002, does not constrain $G_A$ with theory

Note: Placement of SAMPLE band on depends on choice for $G_A$

\[ \% \text{ contrib} = \frac{G_{E,M}^s}{G_{E,M}^p} \times \left( -\frac{1}{3} \right) \times 100 \]
GO Collaboration

California Institute of Technology, Carnegie Mellon University, College of William and Mary, Grinnell College, Institut de Physique Nucléaire d'Orsay, Laboratoire de Physique Subatomique et de Cosmologie-Grenoble, Louisiana Tech University, New Mexico State University, Ohio University, Thomas Jefferson National Accelerator Facility, TRIUMF, University of Illinois, University of Kentucky, University of Manitoba, University of Maryland, University of Winnipeg, University of Zagreb, Virginia Tech, Yerevan Physics Institute

Graduate Students:
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Analysis Coordinator: Fatiha Benmokhtar (Maryland & CMU)
Spokesperson: Doug Beck (UIUC)
GO Collaboration

California Institute of Technology, Carnegie Mellon University,
College of William and Mary, Grinnell College,
Institut de Physique Nucléaire d'Orsay,
Laboratoire de Physique Subatomique et de Cosmologie-Grenoble,
Louisiana Tech University, New Mexico State University, Ohio University,
Thomas Jefferson National Accelerator Facility, TRIUMF, University of Illinois,
University of Kentucky, University of Manitoba, University of Maryland,
University of Winnipeg, University of Zagreb, Virginia Tech,
Yerevan Physics Institute

Grad Students
\( G^0 \) (JLab - Hall C)

- Superconducting toroidal magnetic spectrometer
- 16 “Rings” of detectors

Forward angle mode (completed):
- \( \text{LH}_2: \ E_e = 3.0 \text{ GeV} \)
  - Recoil proton detection \((52^\circ < \theta_p < 76^\circ)\)
    - \( 0.12 \leq Q^2 \leq 1.0 \quad (\text{GeV}/c)^2 \)
- Counting experiment - separate backgrounds via time-of-flight

\[ \text{Elastic cut} \]
**GO: Forward-angle results**

\[ G_E^s + \eta G_M^s = 0 \]

Hypothesis excluded at 89\% C.L.

D.S. Armstrong *et al.*, PRL 95, 092001 (2005)

**EM form factors:**
• Polarized electron beam at 362, 687 MeV, $I \sim 20$-$60$ µA
• Target: 20 cm LH$_2$, LD$_2$
• Elastic, inelastic scattering at $\sim 108^\circ$, $\Delta \Omega \sim 0.5$ sr
• Electron/pion separation using aerogel Cerenkov
Back Angle Apparatus

Detector package

Superconducting Magnet
FPD (1 octant)

Target system installation
Electron Yields

LH2, 687 MeV

LH2, 687 MeV

LH2, 362 MeV

LD2, 687 MeV

LD2, 362 MeV

Electron Yields

(quasi) elastic electrons

background regions

inelastic electrons
**Analysis Strategy**

1. **Blinding Factors** X0.75-1.25
2. **H, D Raw Asymmetries, $A_{\text{meas}}$**
   - Corrections
     - Scaler counting correction
     - Rate corrections (electronics)*
     - Helicity-correlated corrections
     - Background asymmetry
     - Beam polarization*
     - EM radiative correction
3. **Unblinding**
4. **H, D Physics Asymmetries, $A_{\text{phys}}$**
5. **Forward measurements**
   - EM form factors*

*See talk by F. Benmokhtar*
Scaler Counting Problem

- Electronics sorts detector coincidences ($CED_i$ and $FPD_j$) into separate scaler channels
  - FPGA-based system in North American electronics (4 octants)

- Error in FPGA programming, two short (~3 ns) pulses could be sent to scaler in < 7 ns
  - ~1% of events have such pulse pairs (worst case)

- Such pulse pairs sometimes cause scaler to drop or add bits
  - Detailed simulation of ASIC with propagation delays between (flip flop) elements

- Effect on asymmetry is <0.01 $A_{phys}$
  - Test by cutting data
  - compare with French octants, and with data after FPGA fixed
Polarized Beam Properties

- 85.8% Polarization* *(see F. Benmokhtar’s talk)
- Polarization reversal: 30 Hz, random quartets (+---, -+++)
- Slow helicity reversal: $\lambda/2$ wave plate IN and OUT

- Helicity-correlated properties:

<table>
<thead>
<tr>
<th>Beam Parameter</th>
<th>Achieved (OUT-IN)/2</th>
</tr>
</thead>
<tbody>
<tr>
<td>charge asymmetry</td>
<td>0.09 +/- 0.08 ppm</td>
</tr>
<tr>
<td>x position difference</td>
<td>-19 +/- 3 nm</td>
</tr>
<tr>
<td>y position difference</td>
<td>-17 +/- 2 nm</td>
</tr>
<tr>
<td>x angle difference</td>
<td>-0.8 +/- 0.2 nrad</td>
</tr>
<tr>
<td>y angle difference</td>
<td>0.0 +/- 0.1 nrad</td>
</tr>
<tr>
<td>energy difference</td>
<td>2.5 +/- 0.5 eV</td>
</tr>
<tr>
<td>Beam halo (out 6 mm)</td>
<td>&lt; 0.3 x 10^{-6}</td>
</tr>
</tbody>
</table>
Correcting Beam Asymmetries

\[ A_{\text{raw}} = A_{\text{det}} - A_Q + \sum_{i=1,5}^{5} \beta_i \Delta x_i \]

**Determine Slopes from**
- natural beam jitter (regression)
- beam modulation (coil pulsing)

Independent methods provide a cross-check. Each subject to different systematic errors.

**Regression:**
- Natural beam motion, measure yield vs. beam parameter
- Simultaneous fit establishes independent sensitivities

**Coil Pulsing:**
- Induce non-HC beam motion with coils, measure \( \frac{dS}{dC_i}, \frac{dx_i}{dC_i} \)
- Relate slopes to \( \frac{dS}{dx_i} \)

Sensitivities ~5x smaller than at forward angle
Correcting Beam Asymmetries

\[ A_{\text{raw}} = A_{\text{det}} - A_Q + \sum_{i=1,5} \beta_i \Delta x_i \]

Determine Slopes from:

- natural beam jitter (regression)
- beam modulation (coil pulsing)

\[ \frac{1}{Y} \frac{\partial Y}{\partial y} \quad (\% / \text{mm}) \]

Consistent sensitivities from regression and coil pulsing

Net false asymmetry \sim 0.1 \text{ ppm}
Rate Corrections*

- Counting experiment: must correct yields for Random Coincidences & Deadtime before calculating asymmetry

- **Randoms**: small except for 687 MeV LD2 (higher pion rate)
  - Direct (out-of-time) measurement

- **Deadtime corrections**: Simulated complete electronics chain using measured singles rates, etc.

<table>
<thead>
<tr>
<th>Data set</th>
<th>Correction to Yield (%)</th>
<th>Asymmetry Correction (ppm)</th>
<th>systematic error (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>H 362</td>
<td>6</td>
<td>0.3</td>
<td>0.06</td>
</tr>
<tr>
<td>H 687</td>
<td>7</td>
<td>1.4</td>
<td>0.17</td>
</tr>
<tr>
<td>D 362</td>
<td>13</td>
<td>0.7</td>
<td>0.2</td>
</tr>
<tr>
<td>D 687</td>
<td>9</td>
<td>6</td>
<td>1.8</td>
</tr>
</tbody>
</table>

*more details: see F. Benmokhtar's talk
Elastic Asymmetries

- Hydrogen, 687 MeV (similar for all target/energy combos)
- Effect of rate, helicity-correlated corrections:

Pass 1-Raw asymmetries

2-Scaler counting correction

3-Rate correction

4-Linear regression correction
Backgrounds

- Primary background from aluminum target windows
  - about 12% of yield for all target/energy combinations
  - carries same asymmetry as deuterium (within ~ 2%)

- $\pi^-$ contamination in D at 687 MeV
  - 5% contribution (measured), nearly zero asymmetry (measured)

- Hydrogen

$$A_{el} = \frac{A_{\text{meas}} - f_{Al} A_{Al} - f_{\text{other}} A_{\text{other}}}{1 - f_{Al} - f_{\text{other}}}$$

- Deuterium:

$$A_{el} = \frac{A_{\text{meas}} - f_{\text{pion}} A_{\text{pion}} - f_{\text{other}} A_{\text{other}}}{1 - f_{\text{pion}} - f_{\text{other}}}$$

with $f_{\text{other}} \sim 2 \pm 2\%$, $A_{\text{other}} = 0$
Backgrounds: Magnetic Field Scans

- Use simulation *shapes* to help determine dilution factors

**LD$_2$ 687 MeV, CED 8  FPD 13**

- Nominal setting

<table>
<thead>
<tr>
<th>Rate (kHz/µA)</th>
<th>Magnet Current (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.07</td>
<td>2000</td>
</tr>
<tr>
<td>0.06</td>
<td>2500</td>
</tr>
<tr>
<td>0.05</td>
<td>3000</td>
</tr>
<tr>
<td>0.04</td>
<td>3500</td>
</tr>
<tr>
<td>0.03</td>
<td>4000</td>
</tr>
<tr>
<td>0.02</td>
<td>4500</td>
</tr>
<tr>
<td>0.01</td>
<td>5000</td>
</tr>
</tbody>
</table>

- Data
- Simulation total
- Quasielastic (radiated)
- Inelastic (radiated)
- Aluminum (target cell)
- $\pi^-$
- $\pi^0$ decay
Backgrounds: Magnetic Field Scans

• Use simulation shapes to help determine dilution factors

Oct2_eCED_FPD (Hz/μA)

D 13

Magnet Current (A)
Other Corrections to Asymmetries

• Beam normal single-spin asymmetry (transverse asymmetry)
  o Any small transverse component in beam polarization + imperfect detector
    azimuthal symmetry + beam-normal spin asymmetry = false asymmetry
  o Measured asymmetry directly with transverse beam \(\rightarrow\) see J. Mammei’s talk

Net correction < .01 ppm

• EM radiative corrections [Tsai (1971)]

GEANT: Calculate asymmetry based on kinematics at vertex after radiation, compare to tree
level; both calculated after \(dE/dx\) in target

<table>
<thead>
<tr>
<th>Tgt/Energy</th>
<th>(A_0)rc</th>
<th>(A_0)tree</th>
<th>RC correction</th>
</tr>
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<tbody>
<tr>
<td>LD2 687</td>
<td>-46.6</td>
<td>-48.43</td>
<td>3.7%</td>
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<tr>
<td>LD2 362</td>
<td>-13.64</td>
<td>-14.17</td>
<td>3.9%</td>
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<tr>
<td>LH2 687</td>
<td>-36.81</td>
<td>-38.22</td>
<td>3.8%</td>
</tr>
<tr>
<td>LH2 362</td>
<td>-10.1</td>
<td>-10.49</td>
<td>3.9%</td>
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</table>
### Asymmetry Uncertainties (1)

**Hydrogen, 687 MeV**

<table>
<thead>
<tr>
<th></th>
<th>Value (ppm)</th>
<th>Stat (ppm)</th>
<th>Sys Pt (ppm)</th>
<th>Sys Gl (ppm)</th>
<th>Total (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measured Asymmetry</td>
<td>-38.14</td>
<td>2.43</td>
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<td>Background Asymmetry</td>
<td>-38.27</td>
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<td>0.40</td>
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<tr>
<td>Dilution Correction</td>
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<td>0.52</td>
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<td>Transverse Correction</td>
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<td>Beam Polarization</td>
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<td>0.52</td>
<td>0.53</td>
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<td>EM Radiative Correction</td>
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<td>0.84</td>
<td>0.75</td>
<td>2.68</td>
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<tr>
<td>Physics Asymmetry</td>
<td>-46.14</td>
<td>2.43</td>
<td>0.84</td>
<td>0.75</td>
<td>2.68</td>
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</table>
### Asymmetry Uncertainties (2)

**Deuterium, 687 MeV**

<table>
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<tr>
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<th>Value (ppm)</th>
<th>Stat (ppm)</th>
<th>Sys Pt (ppm)</th>
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<tbody>
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<td>Transverse Correction</td>
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<td>0.64</td>
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<td>EM Radiative Correction</td>
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Asymmetry Uncertainties (3)

- **Hydrogen, 362 MeV**

<table>
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<th>Value (ppm)</th>
<th>Stat (ppm)</th>
<th>Sys Pt (ppm)</th>
<th>Sys Gl (ppm)</th>
<th>Total (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measured Asymmetry</td>
<td>-9.941</td>
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<tr>
<td>Transverse Correction</td>
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<td>0.008</td>
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<td>0.385</td>
<td>0.990</td>
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### Asymmetry Uncertainties (4)

**Deuterium, 362 MeV**

<table>
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<tr>
<th></th>
<th>Value (ppm)</th>
<th>Stat (ppm)</th>
<th>Sys Pt (ppm)</th>
<th>Sys Gl (ppm)</th>
<th>Total (ppm)</th>
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<td>Beam Polarization</td>
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<td>0.411</td>
<td>0.197</td>
<td>0.932</td>
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<tr>
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<td>Physics Asymmetry</td>
<td>-17.018</td>
<td>0.813</td>
<td>0.411</td>
<td>0.197</td>
<td>0.932</td>
</tr>
</tbody>
</table>
Determining Form Factors

- Starting from asymmetries, need
  - Effective $Q^2$ determination* - simulation
  - Deuteron model (Schiavilla, priv. comm.)
  - Electromagnetic form factors* (Kelly PRC 70 (2004))
  - Electroweak Radiative corrections
  - check on 2-boson corrections*
    (Arrington, Blunden, Melnitchouk, et al.; Zhou, Kao & Yang, priv. comm.)

- Interpolation of $G_0$ forward angle data:

*see F. Benmokhtar’s talk
Deuteron Model

- Calculation from R. Schiavilla
  includes FSI and 2-body effects

\[ A_{\text{phys}} = a_0 + a_1 G_E^s + a_2 G_M^s + a_3 G_A^e \]
Forward Angle Results - reminder

\[ G_E^s + \eta G_M^s = 0 \]

Hypothesis excluded at 89% C.L.

D.S. Armstrong et al., PRL 95, 092001 (2005)

Correlated systematic

EM form factors:
Backward Angle Results: Preliminary

- Using interpolation of $G_0$ forward measurements

\[ G_0^{E} \]

\[ Q^2 \text{ (GeV}^2\text{)} \]

\[ 0.0 \quad 0.2 \quad 0.4 \quad 0.6 \quad 0.8 \quad 1.0 \]

\[ G_0^{E} \]

\[ 0.0 \quad 0.1 \quad 0.2 \quad -0.1 \quad -0.2 \]

\[ 0.0 \quad 0.2 \quad 0.4 \quad 0.6 \quad 0.8 \quad 1.0 \]

\[ Q^2 \text{ (GeV}^2\text{)} \]

\[ G_0^{M} \]

\[ 0.0 \quad 0.2 \quad 0.4 \quad 0.6 \quad 0.8 \quad 1.0 \]

\[ G_0^{M} \]

\[ -0.2 \quad -0.4 \quad 0.0 \quad -0.6 \]

\[ 0.0 \quad 0.2 \quad 0.4 \quad 0.6 \quad 0.8 \quad 1.0 \]

\[ Q^2 \text{ (GeV}^2\text{)} \]

\[ G_0^{T=1} \]

\[ 0.0 \quad 0.2 \quad 0.4 \quad 0.6 \quad 0.8 \quad 1.0 \]

\[ G_0^{T=1} \]

\[ -2.0 \quad -1.5 \quad -1.0 \quad 0.0 \quad 0.5 \quad 1.0 \]

\[ 0.0 \quad 0.2 \quad 0.4 \quad 0.6 \quad 0.8 \quad 1.0 \]

\[ Q^2 \text{ (GeV}^2\text{)} \]

- Global uncertainties

\[ \text{assumes:} \]

\[ G_{A,NS}^{T=0} (Q^2) = \frac{R_A^{T=0} 3F - D}{2} G_{A}^{\text{dipole}} (Q^2) \]

\[ G_{A,NS}^{T=0} (Q^2 = 0) = 0.070 \]

- Also assumes: no CSV
Contributions to Overall Form Factors

- NEXT STEP: fit 33 separate asymmetry measurements for H, D, He targets
  - at this point, not all data at quite the same level...
  - consistent EM form factors, radiative corrections, CSV...
Preliminary Inelastic Asymmetries

$G^N_A(Q^2)$: Isovector ($\Delta I=1$), spin-flip form factor – encodes space/spin structure in transition to $I=3/2$ resonance, analogous to $G_A(Q^2)$

- LH$_2$ 687 MeV Inelastic:
  
  $[\text{OUT} + \text{IN} = 0.07 \pm 5.1 \text{ ppm}]$

- LD$_2$ 687 MeV Inelastic:
  
  $[\text{OUT} + \text{IN} = -9.9 \pm 10.5 \text{ ppm}]$

Raw data: Backgrounds, radiative corrections not yet included

We seek theory guidance for the deuteron case
Preliminary Pion Asymmetries

- Measure inclusive $\pi^-$ from D target, dominated by photoproduction
- Asymmetry at $Q^2 = 0$ not zero $\Rightarrow$ constrain small asymmetry "$d_\Delta$"
- $d_\Delta$ related to the anomalous $\Delta S = 1$ hyperon decays

LD$_2$ 362 MeV

(OUT – IN)/2 = -0.56 ± 1.03 ppm
[OUT + IN = 3.84 ± 2.15 ppm]

working on systematic uncertainties (~ 0.5 ppm):
Summary

• Comparison of electromagnetic and weak neutral elastic form factors allows determination of strange quark contribution
  - large distance scale dynamics of the sea
• Small positive $G_E^s$ at higher $Q^2$, $G_M^s$ consistent with zero, small quenching of $G_A^e$, consistent with theory
  - next step: global fit to all 33 asymmetries
• First measurement of neutral current $N\Delta$ transition around $Q^2 = 0.3$ GeV$^2$
• First measurement of PV asymmetry in inclusive $\pi^-$ production at low $Q^2$

• see J. Mammei’s talk: First measurements of transverse asymmetries in
  - back angle elastic scattering from H, D targets
  - Inclusive $\pi^-$ production

“Do not infest your mind with beating on the strangeness of this business” - W. Shakespeare (The Tempest)