Polarized Structure Functions:
Proton/Deuteron Measurements in the Resonance Region

Mark K. Jones, Jefferson Lab

Measurement of $A_{p,d}^p$ and $A_{p,d}^d$
at Jefferson Lab in

Collaboration

Univ. Basel, Florida International Univ., Hampton Univ., Univ. of Massachusetts, Univ. of Maryland,
Mississippi State Univ., North Carolina A&T Univ., Univ. of N. C. at Wilmington,
Norfolk State Univ., Old Dominion Univ., S.U. at New Orleans, Univ. of Tel-Aviv,
Jefferson Lab, Univ. of Virginia, Virginia P. I. & S.U., Yerevan Physics Institute

Spokesmen: Oscar A. Rondon (Univ. of Virginia) and Mark K. Jones (Jefferson Lab)

Acknowledge the hard work of Paul McKee, Karl Slifer, Shige Tajima, Frank Wesselmann, Junho Yun and Hongguo Zhu
Experimental set-up in Hall C

Polarized electron beam
5.755 GeV

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

0.6 0.8 1 1.2 1.4 1.6 1.8 2 2.2

\[ W (\text{GeV}) \]

Two HMS momentum settings:
4.7, 4.1 GeV/c

\[ Q^2 \approx 1.3 \text{ GeV}^2 \]
for 0.8 < \( W < 2 \text{ GeV} \)

\[ I \approx 100\text{nA for NH}_3, \text{ND}_3 \]

Beam polarization, \( P_b \)
measured by Møller

\[ P_b = 65.6 \pm 2.6 \text{ for } B_\parallel \]
\[ P_b = 70.9 \pm 1.7 \text{ for } B_\perp \]

Beam charge asym. < 0.1%
Polarized Target

Dynamic Nuclear polarized ammonia (NH₃) and deuterated ammonia (ND₃)

- Target ladder contained carbon (7mm), two NH₃ (or ND₃) cups
- Rotate target can to switch from parallel, B∥, to perpendicular, B⊥, field.
- Polarization can be flipped by 180°.
- Ran ± for equal times.

Average polarization

<table>
<thead>
<tr>
<th></th>
<th>NH₃</th>
<th>ND₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>B∥</td>
<td>68%</td>
<td>15%</td>
</tr>
<tr>
<td>B⊥</td>
<td>70%</td>
<td>20%</td>
</tr>
</tbody>
</table>

Relative systematic error of 4% for ND₃ and 2.5% for NH₃
Extracting Asymmetry

Raw Asymmetry, \( A_{raw} = \frac{N^+ - N^-}{N^+ + N^-} \)

in which \( N^+ \), \( N^- \) are the number of counts normalized by the charge and deadtime for opposite beam helicities.

Parallel and perpendicular asymmetries

\[
A_{\parallel,\perp} = \frac{1}{C_N f_{rc}} \left( \frac{A_{raw}}{P_b P_t} - C_D \right) + A_{rc}
\]

- \( f = \) dilution factor; ratio of rates from polarized nucleons to all nucleons
- \( P_b, P_t = \) beam and target polarizations
- \( C_N, C_D = \) corrections for \(^{15}\text{N} \) asymmetry (not applied yet)
- \( f_{rc}, A_{rc} = \) radiative corrections (sofar applied to proton only)

Use code for polarized scattering in resonances

(I. Akusevich et al.)
Proton Elastic Asymmetry

\[ A_{el} = \frac{K_1 \cos \theta^* + K_2 \frac{G_E}{G_M} \sin \theta^* \cos \phi^*}{G_E^2/G_M^2 + \tau/\epsilon} \]

\[ \theta^*, \phi^* = \text{polar and azimuthal angles between } \vec{q} \text{ and target spin} \]

\[ K_1, K_2 = \text{kinematic factors} \]

<table>
<thead>
<tr>
<th>( \theta^<em>, \phi^</em> )</th>
<th>( B_{\parallel} )</th>
<th>( B_{\perp} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>129°, 180°</td>
<td>( \Delta A_{el}/A_{el} )</td>
<td>0.02</td>
</tr>
<tr>
<td>41°, 162°</td>
<td>( \Delta \frac{G_E}{G_M}/\frac{G_E}{G_M} )</td>
<td>1</td>
</tr>
</tbody>
</table>

\( A_{\parallel} \) used to determine \( P_b P_t \)

\( A_{\perp} \) measure \( \frac{G_E}{G_M} \)

\[ A_{el} = \frac{A_{raw}}{fP_bP_t} - C_N \]

\( C_N = 0.003 \pm 0.001 \) for \( B_{\perp} \)

\( C_N = 0.0015 \pm 0.0015 \) for \( B_{\parallel} \)
Dilution factor for elastic peak

Use carbon for background shape under the elastic peak.

Parallel Target field
- NH$_3$ data
- Elastic $\sigma = 12$ MeV
- Normalize $^{12}$C to $^{15}$N

Perpendicular Target field
- Elastic $\sigma = 17$ MeV
- Normalize $^{12}$C to $^{15}$N

Elastic dilution factor

- Parallel target field
- Perpendicular target field

M. K. Jones at Duality 05 – p.6/18
Measured proton $A_{el}$

- For $B_{||}$, predict $A_{el} = 0.215$
- For $B_{||}$, top and bottom $A_{el}$ disagree.

For $B_{\perp}$, top/bottom $A_{el}$ agree

Extract proton $\frac{G_E}{G_M}$

Use predicted $A_{el}$ to normalize $B_{||}$ target polarizations for top (1.05) and bottom (0.96) cups.
Comparisons to carbon data

Use carbon data to test QFS model.
Example for parallel field.

- Central HMS $p = 4.7$ GeV/c
- Central HMS $p = 4.1$ GeV/c

Compare data to Monte Carlo
Ratio of data to Monte Carlo
Packing fractions

Packing fraction is ratio of NH₃ (or ND₃) to NH₃ + He in cup.

![Graph showing packing fractions for NH₃ and ND₃](image)

<table>
<thead>
<tr>
<th></th>
<th>NH₃</th>
<th>ND₃</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bottom</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>B∥</th>
<th>B⊥</th>
<th>B∥</th>
<th>B⊥</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top</td>
<td>52.4%</td>
<td>58.9</td>
<td>55.2</td>
<td>—</td>
</tr>
<tr>
<td>Bottom</td>
<td>53.2</td>
<td>60.7</td>
<td>56.0</td>
<td>62.1</td>
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</tbody>
</table>
Dilution factors

\( \text{NH}_3 \)

- Hall C fit for \( F_2 \) and \( R \) (M. E. Christy)
- QFS for \( A > 2 \)

\( \text{ND}_3 \)

- Hall C fit for \( F^d_2 \) and \( R^d \) (I. Niculescu)
- QFS for \( A > 2 \), deuteron quasi-elastic
Proton and Deuteron Asymmetries

No correction for $^{15}$N asymmetry applied

Work on radiative correction for deuteron in progress

Relative Systematic errors of 6% and 8% for NH$_3$ and ND$_3$
Proton $A_1$ and $A_2$ versus $W$

$A_\parallel$ and $A_\perp$ transformed using Hall C $F_2$ and $R$ fit (M. E. Christy)
Proton $A_1$ and $A_2$ versus $x$
Proton $g_1^p$ and $g_2^p$
Compare PDFs to $g_1$

GRSV, AAC pdfs evolved to $Q^2 = 1.3$ and have target mass correction.

BSB statistical pdfs evolved to $Q^2 = 1.3$

Need to do quantitative comparison. In progress
Higher twist in $g_2$

$g_2 = g_2^{WW} + \bar{g}_2$  

Twist-2 $g_2^{WW} = -g_1 + \int_x^1 \frac{g_1}{y} \, dy$

Use measured $g_1$ to calculate $g_2^{WW}$
Twist-3 matrix element \(d_2\)

\[
d_2 = \int_0^1 x^2 (2g_1 + 3g_2) \, dx
\]

- Integrated over \(0.29 < x_{bj} < 0.84\)
  \(d_2 = 0.0106 \pm 0.0012\)

- Lattice QCD at \(Q^2 = 5\)
  \(d_2 = 0.0085 \pm 0.0035\)
  QCDSF group, hep-lat/0011091

- SLAC E155 at \(< Q^2 > = 5\)
  \(d_2 = 0.0032 \pm 0.0017\)

- \(1/Q\) dependence of twist-3 implies that SLAC \(d_2\) would increase by 2.
Summary

- Measured proton and deuteron $A_\parallel$ and $A_\perp$ at $Q^2 \approx 1.3$ and $0.8 < W < 2.0$.
- Extracted proton $A_1, A_2, g_1, g_2$.
  - MAID predicts $A_1$ well, $A_2$ less well
  - MAID predicts $g_1$ well at $\Delta$, badly above. $g_2$ well !?!
  - Polarized duality: Qualitative comparison of $g_1$ to PDFs is promising. ⇒ Quantitative comparison in progress.
- Positive $d_2$ measured with 10% error !
- Future ⇒ Approve experiment at JLab in Hall C to measure proton $A_\parallel$ and $A_\perp$ at $2.5 < Q^2 < 6.5$ (O. Rondon, Z. E. Meziani, S. Choi)