The Resonance Spin Structure Measurement at Hall-C and the Future JLab Physics Program

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Topics:
1. Resonance Spin Structure Measurement
2. Spin Asymmetries on the Nucleon Experiment
Resonance Spin Structure

Jefferson Lab RSS Collaboration

Spokespersons: Oscar Rondon (U. of Virginia) and Mark Jones (Jefferson Lab)


Analysis: Paul Mckee, Karl Slifer, S. Tajima, Frank Wesselmann, Junho Yun, Hongguo Zhu, (Peter Bosted, Eric Christy)
The physics goals

• Measure proton and deuteron $A_1(W, Q^2)$ and $A_2(W, Q^2)$ in the nucleon resonance region $(0.8 < W < 2.0)$ at $Q^2 \sim 1.3 \text{ GeV}^2$

• Extract polarized structure functions $g_1$ and $g_2$ and study
  i. $W$-dependence
  ii. Onset of polarized local duality
  iii. Twist-3 effects in $d_2$ matrix element
RSS Experiment in Hall C at JLab

- HMS detects scattered electrons.
- Momentum settings: 4.7, 4.1 GeV/c
- \(<Q^2> = 1.3 \text{ GeV}^2\), 0.8 < W < 2.0 GeV
- I \sim 100\text{nA} for NH\textsubscript{3} and ND\textsubscript{3}
- Beam Polarization (P\textsubscript{B}) by Moller:
  - P\textsubscript{B} = 65.5 \pm 2.6 (%) for B\parallel
  - P\textsubscript{B} = 70.9 \pm 1.7 (%) for B\perp
- Beam charge asym. < 0.1%
Polarized Targets (\(^{15}\text{NH}_3\) and \(^{15}\text{ND}_3\))

- Dynamic Nuclear polarized ammonia
- Target ladder contained carbon disc (7mm thick) and two \(\text{NH}_3\) (or \(\text{ND}_3\)) cups
- 5T Field on target. Magnetic field was either parallel or perpendicular to beam direction.
- Polarization can be flipped by 180°. Ran ± for equal times
- Average target polarization \(P_T = 68\%\) (\(\text{NH}_3\)); 18% (\(\text{ND}_3\))
- Relative systematic error ~2.9%
Proton $A_\parallel$ and $A_\perp$ versus $W$

\[ A_\parallel,\perp = \frac{1}{C_N f_{rc} f P_B P_T} A_{raw} + A_{rc} \]

- $A_{raw}$ = raw asym (counts are normalized by the charge and deadtime)
- $f$ = dilution factor; $P_B, P_T$ = beam and target polarizations
- $C_N$ = corrections for $^{15}$N asymmetry
- $f_{rc}, A_{rc}$ = radiative corrections.

POLRAD (Akusevich et al.) modified to include a fit to our data.
Proton \( A_1 \) and \( A_2 \) versus \( W \)

- \( A_1 \) and \( A_2 \) are extracted from \( A_{\parallel} \) and \( A_{\perp} \) using Hall C \( F_2 \) and \( R \) fits by E. Christy.
Proton $g_1$ and Study of Polarized Duality

NLO PDFs (BSB, GRSV, AAC) have been evolved to $Q^2 = 1.3 \text{ GeV}^2$, and have target mass corrections.
Proton $g_1$ and Study of Polarized Duality

- Quoted errors are for the data only. Phenomenology systematics for the PDFs ($\pm 0.06$ for the global ratio) needs to be added.

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<th>W range</th>
<th>Ratio of Integrals (PDF and data fit)</th>
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<td>Delta</td>
<td>1.12--1.30</td>
</tr>
<tr>
<td>R1</td>
<td>1.30--1.40</td>
</tr>
<tr>
<td>R2</td>
<td>1.40--1.69</td>
</tr>
<tr>
<td>R3</td>
<td>1.69--1.81</td>
</tr>
<tr>
<td>Global</td>
<td>1.08--1.91</td>
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4.80 ± 0.68
1.34 ± 0.07
0.78 ± 0.04
0.84 ± 0.04
1.17 ± 0.06
Proton $g_1$ and Study of Polarized Duality

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- Quoted errors are for the data only. Phenomenology systematics for the PDFs (±0.06 for the global ratio) needs to be added.
- Local duality is not observed in proton $g_1$ at $Q^2 = 1.3 \text{ GeV}^2$.
- The global ratio becomes $1.42 \pm 0.07$ if large-$x$ resummations for the PDFs (Bianchi et al, PRD 69, 014505 (2004)) are included.
Proton $g_2$ and Higher Twist

Use measured $g_1$ to calculate $g_{WW}$

$g_2 = g_{WW}^2 + \bar{g}_2$; Twist 2: $g_{WW}^2(x, Q^2) = -g_1(x, Q^2) + \int_x^1 \frac{dy}{y} g_1(y, Q^2)$
Twist-3 Matrix Element $d_2$

$$d_2 = \int_0^1 2x^2 (g_1 + \frac{3}{2}g_2) dx$$

Elastic contribution is large at $Q^2 = 1.3$ ($d_2_{\text{elas}} = 0.03$) but it’s small at $Q^2 = 5.0$ ($d_2_{\text{elas}} = 0.00013$).

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<tr>
<th>Experiment</th>
<th>$Q^2$</th>
<th>Note</th>
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<tr>
<td>JLab RSS</td>
<td>1.3</td>
<td>0.29 $&lt; x &lt; 0.84$</td>
</tr>
<tr>
<td>SLAC E-155</td>
<td>5.0</td>
<td></td>
</tr>
<tr>
<td>LQCD Calc.</td>
<td>5.0</td>
<td>Göckeler et al, PRD72, 054507 (2005)</td>
</tr>
<tr>
<td>JLab SANE</td>
<td>3, 4, 5, 6</td>
<td>Data taking in 2008 Expected error is better than ±0.0012</td>
</tr>
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</table>
Deuteron $g_1$ and $g_2$ versus $x$

- All corrections are applied except for the radiative corrections.

Preliminary

NOT final

- $g_1$
- $g_2$

$\times_{Bj}$
Spin Asymmetries on the Nucleon Experiment

Jefferson Lab SANE Collaboration

(Spokespersons: Oscar Rondon (U. of Virginia), Zein-Eddine Meziani (Temple), Seonho Choi (Seoul))

Basel, F.I.U, Hampton, IHEP Protvino, Kent State, Norfolk State, N.C. A&T, Renesselaer Polytechnic, St. Norbert, Temple, TJNAF, University of Virginia, William&Mary, Yerevan

• Measure proton $A_1$ and $g_2$ with large acceptance detector (BETA) in range $2.5 < Q^2 < 6.5$ and $0.3 < x < 0.8$

• Study $x$ and $Q^2$ dependence, Twist-3 effect, moments of $g_2$ and $g_1$, Test polarized local duality for $W > 1.4$

• Will take data in Hall C at JLab in 2008
Experimental Setup

- Polarized Electron Beam
  - $P_{\text{Beam}} = 75\%$
  - $E_{\text{Beam}} = 4.8, 6.0 \text{ GeV}$
- UVa Polarized Target (NH$_3$)
  - $P_T = 75\%$
  - Target polarization parallel ($180^\circ$) or perpendicular ($80^\circ$)
- Electron Detector (BETA) @ $40^\circ$
  - Large Acceptance (194mSr)
- Electron Spectrometer (HMS)
  - Background Studies
  - BETA Calibration (ep elastic)
Big Electron Telescope Array (BETA)

- **Lead Glass Calorimeter**
  - $\frac{\Delta E}{E} = 5\%/\sqrt{E}$
  - Large Solid Angle (194mSr)
  - Highly segmented 1744 blocks (4x4x40cm)

- **Gas Cerenkov**
  - $\pi/e$ separation
  - 1000:1 rejection factor

- **Lucite Hodoscope Array**
  - Redundant PID, Tracking info when combined with Calorimeter
Expected Results for Proton $g_2$ and $A_1$

![Graph showing expected results for proton $g_2$ and $A_1$.]
Expected Results (x and $Q^2$ dependence)

$d_2$ will be measured at $Q^2 = 3.5$ and $5.5$ GeV$^2$ with high precision.
Summary of RSS and SANE experiments

- **RSS** (Proton data analysis nearly done)
  - Extracted proton spin asymmetries \(A_1, A_2\) and structure functions \(g_1, g_2\) in the resonance region.
  - Studied polarized duality in the resonance region, twist-3 effect, and \(d_2\) matrix element
  - Deuteron and Neutron SSFs to be extracted.
  - A PRL (for the proton results) to be submitted soon

- **SANE** (Future experiment)
  - Will measure proton \(A_1\) and \(g_2\) with large acceptance detector (BETA) in range \(2.5 < Q^2 < 6.5\) and \(0.3 < x < 0.8\)
  - Study \(x\) and \(Q^2\) dependence, twist-3 effect, moments of \(g_2\) and \(g_1\), test polarized local duality for \(W > 1.4\)
  - Will take data in Hall C at JLab in 2008
Packing Fraction and Dilution Factor

Packing Fraction (PF) is the ratio of NH$_3$ to (NH$_3$ + He)

Dilution Factor: $f(W) = \frac{\# \text{Events(free proton)}}{\# \text{Events(total)}}$

Hall C fits for F$_2$ and R (M.E. Christy)
QFS for $A>2$

- PF for each target cell was determined by comparing the simulated W spectrum with data.
- Measured NH$_3$ PFs: 52-61\%, Systematic error in PFs: \(<2\%\)
How to get $A_1, A_2, g_1,$ and $g_2$

- Full expression for RSS analysis

$$A_1 = \frac{Q^2 (\nu \cot(\theta/2) + E' \sin \theta) \cos \phi A_\parallel + E'(1 + \cos \theta)A_\perp}{D'}$$

$$A_2 = \frac{\sqrt{Q^2} (Q^2 \cot(\theta/2) - \nu E' \sin \theta) \cos \phi A_\parallel + (Q^2 + \nu(E + E' \cos \theta))A_\perp}{E' \sin \theta \cos \phi (Q^2 + 2E(E + E' \cos \theta))}\frac{D'}{D'}$$

- $D'(E, E', \theta, R) = \text{depolarization factor}$

- Have both SA's and SF's calculated using above.

$$g_1 = \frac{F_1}{1 + \gamma^2}(A_1 + \gamma A_2)$$

$$g_2 = \frac{F_1}{1 + \gamma^2}(A_2/\gamma - A_1)$$

$$\gamma = \sqrt{\frac{Q^2}{\nu^2}}$$

$F_1 = F_2(1 + \gamma^2)/2x/(1 + R)$

Recent Fits to F2 and R data in the resonance region were used to obtain $F_1$
Fit to the Proton SA's

- Four Breit-Wigner resonance shapes plus DIS background
- Fit $A_1$ and $A_2$ independently
- Reduced $\chi^2 \sim 1.3 - 1.5$ for 12 d.o.f.
Elastic contribution to $d_2$

$$d_2 = \int_0^1 2x^2(g_1 + \frac{3}{2}g_2)dx$$

A large elastic contribution to $d_2$ at $Q^2 = 1.3$ GeV$^2$
Next: Neutron Spin Structure

- Extract neutron from $p$ and $d$
- Bodek-Ritchie version of Atwood-West smearing
  - generate smeared proton $A_\parallel, A_\perp$ from $g_1, g_2$
  - subtract from deuteron $A_\parallel, A_\perp$ to form smeared neutron quantities
  - unsmear neutron using iterated fit to model