Probing the Spin Structure of the Neutron:

E12-06-121: $d_2$ and $g_2$ for the Neutron

Spokespeople:
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Jefferson Lab
• Hall C: SHMS + HMS
• Two beam energies:
  → 11 GeV/c (production)
  → 2.2 GeV/c (calib.)
• Beam Current
  → 30 uA (production)
  → 60 uA (max, calib.)
• Target: 40 cm Polarized 3He
• Each arm measures an absolute polarized cross section independent of the other arm \((g_1, g_2)\)
  → \(d_2(Q^2) = \int_0^1 x^2 [2g_1(x, Q^2) + 3g_2(x, Q^2)] dx\)
• SHMS collects data at
  → \(\Theta = 11^\circ, 13.3^\circ, 15.5^\circ\) and \(18.0^\circ\) for 125 hrs each
  → data from each setting divided into 4 bins
• HMS collects data at
  → \(\Theta = 13.5^\circ, 16.4^\circ, 20.0^\circ\) and \(25.0^\circ\) for 125 hrs each
Projected results for E12-06-121

\(Q^2\) evolution of \(d_2^n\) in a region where models are thought to be accurate.

Direct overlap with 6 GeV Hall A measurements.

Projected \(g_2^n\) points are vertically offset from zero along lines that reflect different (roughly) constant \(Q^2\) values from 2.5—7 GeV^2.
Standard Hall C Detector Packages

- **SHMS ('default' detector package)**
  - Hodoscopes, Wire chambers, NGC, Calorimeter
  - HGC tank remains installed: may pump to vacuum, or fill with Argon for auxiliary PID

- **HMS ('default' detector package)**
  - Hodoscopes, Wire chambers, Calorimeter
  - HGC fill with Argon, or C4F10 (sub-atmosphere)

- **DAQs**
  - Standard DAQ and triggers

- **See also:** [Spectrometer and Detector Systems talk](#)
Nominal Beam Requirements

• Beam Characteristics
  » See 'Performance Requirements' slide in A1n overview and running conditions for general shared requirements.
    → 1-pass, 5-pass requested (see upcoming slide for more details)
    → Beam polarization: 80%
    → < 50 ppm charge asym (average over ~ 1–2 hr run)
    → 30 uA (max) on glass cell targets
    → 60 uA (max) on solid targets
Nominal Target Requirements

- Polarized $^3\text{He}$ Target Requirements
  » See 'Performance Requirements' slide in A1n overview and running conditions for general shared target requirements.
    -> 55% polarization
    -> 30 uA beam current capability
    -> ~0.1 spin angle measurement (2 mrad)
      » Challenging, but achievable

- Target Ladder components
  -> Polarized $^3\text{He}$ production cell (40cm)
  -> Reference cell:
    » vacuum, $\text{H}_2$, $^3\text{He}$, Nitrogen
  -> Optics foils (7)
  -> Single-carbon foil
  -> Carbon-hole (alignment, raster checks)
Beam Time Allocation

- PAC 36 approved E12-06-121 for requested 700 PAC hours (29 PAC days)
  → 5-pass beam (nominal 11.0 GeV/c) for ~ 676 PAC hours
  → 1-pass beam (nominal 2.2 GeV/c) for ~ 20 PAC hours + pass change → 5-pass
    » [*] ~ 20 calibration hours include data to be shared w/ A1n (elastics, optics, etc.)

- 1-pass Running (Calibrations) [~20 PAC hours]
  → Optics [2 PAC hours*]
  → H(e,e'p) elastics, C, $^3$He elastic, QE calibrations [15 PAC hours*]
  → BCM, BPM calibrations [2 PAC hours*]

- Pass change 1→ 5 [~4 PAC hours*]

- 5-pass Running (Production) [~676 PAC hours]
  → Production [~600 PAC hours]
  → Optics, BCM, Misc. [18 PAC hours]
  → Target polarization measurements (4% of production) [24 PAC hours]
  → Reference cell runs ($N_2$, $^3$He, vacuum) [8 PAC hours]
  → Positive polarity [16 PAC hours]
  → Moller measurements (x4) [12 PAC hours]
Fallback / Contingency Plans

- Original proposal approved by PAC30 was more conservative:
  - Beam
    - 10 uA
    - 80% polarized
  - Target: 2008 params
    - 40 cm long
    - 50% polarization
  - 3 'paired' kinematic groups (instead of 4)
    - ~200 hours for each pair

- Worst case:
  - Fall back to these params and we still have a viable measurement.

- See also:
  - Section 5 of PAC36 Update (last few paragraphs)
Charge Items Addressed

1. What are the running conditions for both experiments
   → Please state clearly the maximum current being used and the target dimensions.

2. What is the operational status/performance requirements of the equipment needed by the experiments. Precisely:
   → a) 3He target
      Provide the targets configuration needed, performance requirements and status.
Supporting Documentation

• Supporting Documentation
  → PAC30 Proposal
  → PAC36 Update

• Polarized $^3$He ERR Page
  Supporting Documentation

• E06-014 (2009 d2n Exp.) Wiki
Backup Slides
Magnetic Field Direction

Longitudinal Field: - air floating compass (left)
- needle compass (above)
\[ \Delta \Theta < 2 \text{ mrad} (< 0.1 \text{ degree}) \]

Transverse Field: - air floating compass (left)
\[ \Delta \theta \sim 1 \text{ mrad} (~0.05 \text{ degree}) \]

C. Dutta, Ph. D. Thesis, UKy, 2010
Production Kinematics for HMS

Table 4: Expected rates for the three HMS settings. The uncertainties for \( A_{\parallel} \) and \( A_{\perp} \) are statistical only.

<table>
<thead>
<tr>
<th>( \theta_0 ) [°]</th>
<th>( E'_{\text{cent}} ) [GeV]</th>
<th>( Q^2 ) [GeV²]</th>
<th>( x )</th>
<th>( W ) [GeV]</th>
<th>( e^- ) rate [Hz]</th>
<th>( \pi^- ) rate [Hz]</th>
<th>( t_{\parallel} ) [hrs]</th>
<th>( t_{\perp} ) [hrs]</th>
<th>( \Delta A_{\parallel} ) [( \cdot 10^{-4} )]</th>
<th>( \Delta A_{\perp} ) [( \cdot 10^{-4} )]</th>
</tr>
</thead>
<tbody>
<tr>
<td>13.5</td>
<td>4.305</td>
<td>2.617</td>
<td>0.208</td>
<td>3.293</td>
<td>954</td>
<td>765</td>
<td>8</td>
<td>117</td>
<td>2.0</td>
<td>0.6</td>
</tr>
<tr>
<td>16.4</td>
<td>5.088</td>
<td>4.555</td>
<td>0.410</td>
<td>2.727</td>
<td>218</td>
<td>15</td>
<td>12</td>
<td>113</td>
<td>3.9</td>
<td>1.2</td>
</tr>
<tr>
<td>20.0</td>
<td>4.000</td>
<td>5.31</td>
<td>0.404</td>
<td>2.951</td>
<td>76</td>
<td>66</td>
<td>10</td>
<td>115</td>
<td>6.0</td>
<td>1.8</td>
</tr>
<tr>
<td>25.0</td>
<td>2.500</td>
<td>5.15</td>
<td>0.323</td>
<td>3.417</td>
<td>20</td>
<td>84</td>
<td>13</td>
<td>112</td>
<td>10.7</td>
<td>3.1</td>
</tr>
</tbody>
</table>

- Rate table from PAC36
  → 30 uA beam
  → 55% polarization
  → Assumed 60 cm long cell

- Current target
  → 40 cm long cell

- As discussed in the PAC36 update, we have been conservative on our statistical run times and are not statistics limited, even with the shorter production cell.
Production Kinematics for SHMS

Table 3: Kinematic bins and expected rates for the SHMS. The uncertainties for $A_\parallel$ and $A_\perp$ are statistical only.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>$\theta_0 = 11^\circ$</td>
<td>7.112</td>
<td>2.875</td>
<td>0.394</td>
<td>2.305</td>
<td>1058</td>
<td>11</td>
<td>12</td>
<td>113</td>
<td>2.0</td>
<td>0.5</td>
</tr>
<tr>
<td>$E'_{\text{cent}} = 7.5$ GeV</td>
<td>7.709</td>
<td>3.116</td>
<td>0.504</td>
<td>1.988</td>
<td>708</td>
<td>3.1</td>
<td>12</td>
<td>113</td>
<td>2.3</td>
<td>0.7</td>
</tr>
<tr>
<td>$\theta_0 = 13.3^\circ$</td>
<td>6.647</td>
<td>3.922</td>
<td>0.480</td>
<td>2.267</td>
<td>268</td>
<td>3.1</td>
<td>12</td>
<td>113</td>
<td>3.5</td>
<td>1.0</td>
</tr>
<tr>
<td>$E'_{\text{cent}} = 7.0$ GeV</td>
<td>7.203</td>
<td>4.250</td>
<td>0.596</td>
<td>1.941</td>
<td>139</td>
<td>0.8</td>
<td>12</td>
<td>113</td>
<td>4.8</td>
<td>1.5</td>
</tr>
<tr>
<td>$\theta_0 = 15.5^\circ$</td>
<td>5.997</td>
<td>4.798</td>
<td>0.511</td>
<td>2.342</td>
<td>96</td>
<td>1.9</td>
<td>12</td>
<td>113</td>
<td>5.7</td>
<td>1.8</td>
</tr>
<tr>
<td>$E'_{\text{cent}} = 6.3$ GeV</td>
<td>6.496</td>
<td>5.197</td>
<td>0.614</td>
<td>2.037</td>
<td>49</td>
<td>0.47</td>
<td>12</td>
<td>113</td>
<td>7.8</td>
<td>2.5</td>
</tr>
<tr>
<td>$\theta_0 = 18.0^\circ$</td>
<td>5.348</td>
<td>5.756</td>
<td>0.542</td>
<td>2.397</td>
<td>35</td>
<td>1.1</td>
<td>12</td>
<td>113</td>
<td>9.5</td>
<td>3.1</td>
</tr>
<tr>
<td>$E'_{\text{cent}} = 5.6$ GeV</td>
<td>5.790</td>
<td>6.235</td>
<td>0.637</td>
<td>2.106</td>
<td>17</td>
<td>0.25</td>
<td>12</td>
<td>113</td>
<td>13</td>
<td>4.4</td>
</tr>
</tbody>
</table>

- Table from PAC36 update
  → Same considerations as noted on prior slide apply.
**Systematic Error Table**

<table>
<thead>
<tr>
<th>Item description</th>
<th>Subitem description</th>
<th>Relative uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target polarization</td>
<td></td>
<td>1.5 %</td>
</tr>
<tr>
<td>Beam polarization</td>
<td></td>
<td>3 %</td>
</tr>
<tr>
<td>Asymmetry (raw)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Target spin direction (0.1°)</td>
<td></td>
<td>$&lt; 5 \times 10^{-4}$</td>
</tr>
<tr>
<td>- Beam charge asymmetry</td>
<td></td>
<td>$&lt; 50$ ppm</td>
</tr>
<tr>
<td>Cross section (raw)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- PID efficiency</td>
<td></td>
<td>$&lt; 1$ %</td>
</tr>
<tr>
<td>- Background Rejection efficiency</td>
<td></td>
<td>$\approx 1$ %</td>
</tr>
<tr>
<td>- Beam charge</td>
<td></td>
<td>$&lt; 1$ %</td>
</tr>
<tr>
<td>- Beam position</td>
<td></td>
<td>$&lt; 1$ %</td>
</tr>
<tr>
<td>- Acceptance cut</td>
<td></td>
<td>2-3 %</td>
</tr>
<tr>
<td>- Target density</td>
<td></td>
<td>$&lt; 2$ %</td>
</tr>
<tr>
<td>- Nitrogen dilution</td>
<td></td>
<td>$&lt; 1$ %</td>
</tr>
<tr>
<td>- Dead time</td>
<td></td>
<td>$&lt; 1$ %</td>
</tr>
<tr>
<td>- Finite Acceptance cut</td>
<td></td>
<td>$&lt; 1$ %</td>
</tr>
<tr>
<td>Radiative corrections</td>
<td></td>
<td>$\leq 5$ %</td>
</tr>
<tr>
<td>From $^3$He to Neutron correction</td>
<td></td>
<td>5 %</td>
</tr>
<tr>
<td>Total systematic uncertainty (for both $g_2^q(x, Q^2)$ and $d_2(Q^2)$)</td>
<td></td>
<td>$\leq 10$ %</td>
</tr>
<tr>
<td>Estimate of contributions to $d_2$ from unmeasured region</td>
<td>$\int_{0.003}^{0.23} \frac{d_2}{d_2} , dx$</td>
<td>$4.8 \times 10^{-4}$</td>
</tr>
<tr>
<td>Projected absolute statistical uncertainty on $d_2$</td>
<td></td>
<td>$\Delta d_2 \approx 5 \times 10^{-4}$</td>
</tr>
<tr>
<td>Projected absolute systematic uncertainty on $d_2$ (assuming $d_2 = 5 \times 10^{-5}$)</td>
<td></td>
<td>$\Delta d_2 \approx 5 \times 10^{-4}$</td>
</tr>
</tbody>
</table>

- **PREx-II, CREx ERR accepted < 0.1 ppm Charge Asym requirement as achievable**
- **Target spin direction precision achievable (see backup slide)**
E12-06-121: $d_2^n, g_2^n$

- Directly measure the $Q^2$ dependence of the neutron $d_2^n(Q^2)$ at $Q^2 \approx 3, 4, 5, 6$ GeV$^2$ with the new polarized $^3$He target.
  → The new Hall C SHMS is ideally suited to this task!
- Doubles number of precision data points for $g_2^n(x, Q^2)$ in DIS region.
  → $Q^2$ evolution of $g_2^n$ over $(0.23 < x < 0.85)$
- $d_2$ is a clean probe of quark-gluon correlations / higher twist effects
- Connected to the color Lorentz force acting on the struck quark (Burkardt)
  → same underlying physics as in SIDIS $k_\perp$ studies
- Investigate the present discrepancy between data and theories.

- Spokespeople: T. Averett, W. Korsch, Z.E. Meziani, B. Sawatzky