Probing the Spin Structure of the Neutron:

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

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On behalf of the E06-014 & E12-06-121 Collaborations

Hall C Users Meeting
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$d_2: A clean probe of quark-gluon correlations$

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

- $d_2$ is a clean probe of quark-gluon correlations / higher twist effects
  - $d_2$ is the 2nd moment of a sum of the spin structure functions
  - matrix element in the Operator Product Expansion
    - it is cleanly computable using Lattice QCD
- Theory and data disagree for neutron
  - signs disagree, several \(\sigma\) separation
  - Significant motivation for E06-014 in Hall A (2009)
- Connected to the color Lorentz (transverse) force acting on the struck quark (Burkardt)
  - same underlying physics as in SIDIS \(k_\perp\) studies
- Can also extract “Color Polarizabilities” (lower $Q^2$ interpretation)
$d_2: A$ clean probe of quark-gluon correlations

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

**Posik et al., PRL 113 022002 (2014)**

- Our 2014 results are consistent with Lattice QCD prediction → now in tension with SLAC data
- \(d_2n\) extracted at
  - \(<Q^2> \sim 3.3 \text{ GeV}^2\) (E=4.7 GeV data)
  - \(<Q^2> \sim 4.3 \text{ GeV}^2\) (E=5.9 GeV data)
- Shaded boxes in inset are systematic uncertainties
- Low-x contribution (0.02 < x < 0.25) is provided by fits to world data (small impact)
- \(^3\text{He} \rightarrow \text{neutron correction using eff. polarization method applied to } d_2\)
- E06-014 archival paper nearly final (D. Flay, et al.)
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Addendum bonus: $A_1^n$ and $(\Delta q + \Delta \bar{q})/(q + \bar{q})$ flavor extraction results:
→ Parno et al., Phy Let B DOI: 10.1016/j.physletb.2015.03.067

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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 $(0.23 < x < 0.85)$

Spokespeople: T. Averett, W. Korsch, Z.E. Meziani, B. Sawatzky
E12-06-121: $d_2^n, g_2^n$

- **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

- **Hall C:** SHMS + HMS
- One beam energy $\rightarrow 11$ GeV
- Each arm measures an abs. cross section independent of the other arm.
- Experiment split into four pairs of 125 hour runs with spectrometer
Impact of Planned $^3$He Target Upgrade

- Polarized $^3$He target group has developed a new target design
  - “high-luminosity GEN-II” target cell
  - 60cm long target cell (2008 cell was 40cm)
  - dual transfer tube allowing active convective circulation of polarized gas
  - *Ultimate goal* for this design is to reach 60% polarization @ 60 µA

- E12-06-121 collaboration assumed 55% polarization @ 30 µA for PAC36 (a “grading PAC” in Summer 2010)
  - Extended cell + 30 µA operation allows significant extension of experimental reach (FOM increase ~4—5x). Additional kinematic points were added to take advantage of new design.
    - *Moderate luminosity goal*. Easily adapts to accommodate unforeseen issues, or add additional points if target perform to final spec.
  - 55% polarization @ 15 uA is sufficient to achieve original (PAC30) goals (even with original 40cm cell)
    - (Deep fallback plan)
Projected results for E12-06-121

Q2 evolution of $d_2^n$ in a region where models are thought to be accurate.

Direct overlap with 6 GeV Hall A measurements.
E06-014: The Neutron $d_2$ (Hall A)

- A measurement of the neutron $d_2$
  - Polarized $^3$He target
  - Large acceptance detector to measure asyms (BigBite)
  - High-precision device to measure unpol. x-sec (HRS)
  - Focus: $d_2$, $g_2$ on the neutron
    - extracted $A_1$, $g_1$ as well
The E06-014 Experiment

- A 4.75 and 5.9 GeV polarized electron beam scattering off a polarized $^3$He target
- Measure unpolarized cross section for $^3\overline{He}(e, e')$ reaction $\sigma_0^{^3He}$ in conjunction with the parallel asymmetry $A_{\perp}^{^3He}$ and the transverse asymmetry $A_{\parallel}^{^3He}$ for $0.23 < x < 0.65$ with $2 < Q^2 < 5$ GeV$^2$.
  - Asymmetries measured by BigBite
  - Absolute cross sections measured by L-HRS
- Determine $d_2^n$ using the relation

$$d_2(x, Q^2) = x^2[2g_1(x, Q^2) + 3g_2(x, Q^2)]$$

$$= \frac{MQ^2}{4\alpha^2} \frac{x^2y^2}{(1-y)(2-y)} \sigma_0 \left[ \left( \frac{3}{(1-y)\sin\theta} + \frac{4}{y} \tan\frac{\theta}{2} \right) A_{\perp} + \left( \frac{4}{y} - 3 \right) A_{\parallel} \right]$$

where,

$$A_{\perp} = \frac{\sigma_{\perp\rightarrow} - \sigma_{\perp\rightarrow}}{2\sigma_0}$$

$$A_{\parallel}^{^3He} = \frac{\Delta_{\perp}}{P_bP_t \cos \phi}$$

$$\Delta_{\perp} = \frac{N_{\perp\rightarrow} - N_{\perp\rightarrow}}{N_{\perp\rightarrow} + N_{\perp\rightarrow}}$$

$$A_{\parallel} = \frac{\sigma_{\parallel\rightarrow} - \sigma_{\parallel\rightarrow}}{2\sigma_0}$$

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$$\Delta_{\parallel} = \frac{(N_{\parallel\rightarrow} - N_{\parallel\rightarrow})}{(N_{\parallel\rightarrow} + N_{\parallel\rightarrow})}$$
Floor configuration for $d_2^n$
$A_1$ for Neutron

$p$QCD with spin only

$p$QCD with orbital angular momentum

Final

Parno et al., Phy Let B DOI: 10.1016/j.physletb.2015.03.067
Spin-only pQCD is strongly disfavored

Must go higher in $x$ to distinguish between other models $(\Delta u + \Delta \bar{u})/(u + \bar{u})$ and $(\Delta d + \Delta \bar{d})/(d + \bar{d})$

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$x^2 g_1$ for $^3$He
$x^2 g_2$ for $^3$He

- Panel (a) shows comparison to world data
- Panel (b) is zoomed on y-axis to show error bars

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Archival paper in progress (David Flay ~ Temple U.)

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