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Polarized Deep Inelastic Scattering

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Summary

Precision Measurement of the Neutron d_2 : Probing the Lorentz Color Force

D. Flay¹, M. Posik¹, D. Parno^{2,3}

¹Temple University ²CENPA, University of Washington ³Carnegie Mellon University

PANic11, 7/28/11

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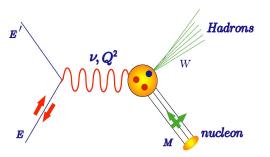
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Polarized DIS



- Scatter longitudinally-polarized electrons off of a longitudinally (or transversely) polarized nucleon
- They interact via an exchanged virtual photon
- Probes the spin content of the nucleon
- We measure physics observables like the electron's scattering cross-section and asymmetries



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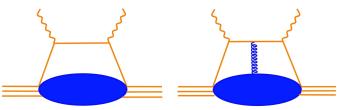
Quark-Gluon Correlations

The Spin Structure Function g_2

- We want to investigate how quarks and gluons interact inside the nucleon
- The g_2 structure function provides a direct probe into such interactions

$$g_2\left(x,Q^2\right) = g_2^{WW}\left(x,Q^2\right) + \overline{g}_2\left(x,Q^2\right)$$

 Seen in the imaginary part of virtual Compton scattering:



Leading Twist = Twist 2

Higher Twist = Twist 3

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d_2^n From the Spin Structure Functions

• d_2^n is determined as the second moment of a linear combination of the spin structure functions g_1 and g_2

$$d_{2}^{n}(Q^{2}) = \int_{0}^{1} x^{2} \left[2g_{1}(x, Q^{2}) + 3g_{2}(x, Q^{2}) \right] dx$$
$$= 3 \int_{0}^{1} x^{2} \overline{g}_{2}(x, Q^{2}) dx$$

 Gives a direct measure of twist-3 effects in the neutron at leading order Quark-Gluon Correlations The Lorentz Color

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The Lorentz Color Force

• $Q^2 > 1~{
m GeV^2}~$ The expression for the transverse (color) force on the active quark right after it is struck by the virtual photon in the interaction reads:

$$F^{y}(0) \equiv -\frac{\sqrt{2}}{2P^{+}}\langle P, S \mid \bar{\psi}_{q}(0) G^{+y}(0) \gamma^{+} \psi_{q}(0) \mid P, S \rangle$$
$$= -\frac{1}{2} M^{2} d_{2}^{n}$$

 d₂ⁿ is a measure of this transverse Lorentz color force (M. Burkardt, hep-ph/0905.4079v1) What is d_2^n ?

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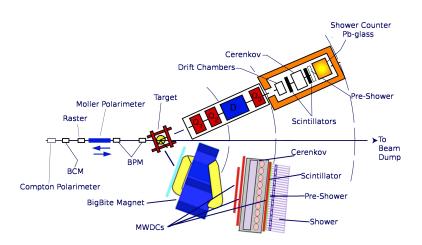
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Kinematic Coverage

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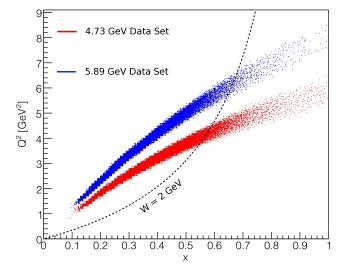
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Electron Beam Polarization

- Two methods: Møller and Compton measurements
- Combine both methods to acheive an error of $\sim 1.6\%$

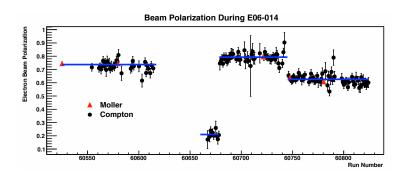


Figure: Compton data analysis by D. Parno. Plot from D. Parno's thesis.

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³He Target Polarization

- NMR measurement every four hours (target chamber)
- EPR at every spin rotation (pumping chamber)

Target Polarization During E06-014

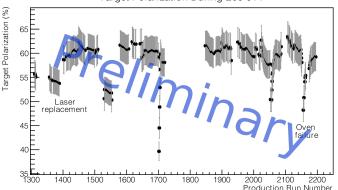


Figure: Target polarization analysis by Y. Zhang.



Measurements

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The Measurement of d_2^n

 Combine our measured cross-sections and asymmetries:

$$\begin{array}{lcl} d_2^n & = & \int_0^1 dx \frac{MQ^2}{4\alpha^2} \frac{x^2y^2}{\left(1-y\right)\left(2-y\right)} {\color{red}\sigma_0} \\ & \times & \left[\left(3\frac{1+\left(1-y\right)\cos\theta}{\left(1-y\right)\sin\theta} + \frac{4}{y}\tan\left(\theta/2\right)\right) {\color{blue}A_\perp} + \left(\frac{4}{y}-3\right) {\color{blue}A_\parallel} \right] \end{array}$$

$$A_{\parallel} = \frac{\sigma^{\downarrow \uparrow \uparrow} - \sigma^{\uparrow \uparrow \uparrow}}{\sigma^{\downarrow \uparrow \uparrow} + \sigma^{\uparrow \uparrow \uparrow}} \quad A_{\perp} = \frac{\sigma^{\downarrow \Rightarrow} - \sigma^{\uparrow \Rightarrow}}{\sigma^{\downarrow \Rightarrow} + \sigma^{\uparrow \Rightarrow}} \quad \sigma_{0} = \frac{N}{(Q/e)\rho LT\varepsilon} \frac{1}{w \Delta E' \Delta \Omega \Delta Z}$$

$$\uparrow, \downarrow = e^-$$
 beam spin $\uparrow, \Rightarrow =$ Target spin

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Cross Sections (1) E = 4.73 GeV Data

³He Cross Section (E = 4.73 GeV, θ = 45°)

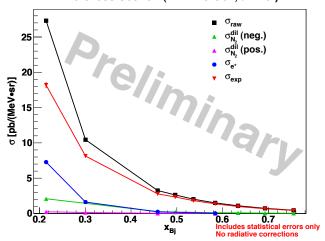


Figure: Cross section analysis by D. Flay.



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Cross Sections (2) E = 5.89 GeV Data

³He Cross Section (E = 5.89 GeV, θ = 45°)

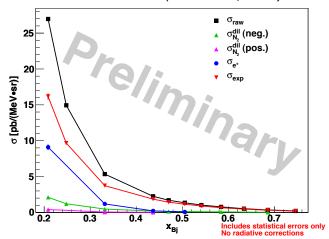


Figure: Cross section analysis by D. Flay.



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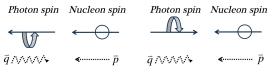
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Asymmetries (1)

A₁: The Virtual Photon-Nucleon Asymmetry



Parallel spins: $\sigma_{\scriptscriptstyle 3/2}$

Anti-parallel spins: $\sigma_{1/2}$

Figure: Reproduced from D. Parno's thesis.

• En route to determining d_2^n , we can evaluate the virtual photon-nucleon asymmetry:

$$\begin{array}{lll} A_{1}\left(x,Q^{2}\right) & \equiv & \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} \\ & = & \frac{g_{1}\left(x,Q^{2}\right) - \gamma^{2}g_{2}\left(x,Q^{2}\right)}{F_{1}\left(x,Q^{2}\right)} \\ & = & \frac{1}{D\left(1 + \eta\xi\right)} \frac{A_{\parallel} - \frac{\eta}{d\left(1 + \eta\xi\right)} A_{\perp}}{A_{\parallel} + \frac{\eta}{d\left(1 + \eta\xi\right)}} \end{array}$$

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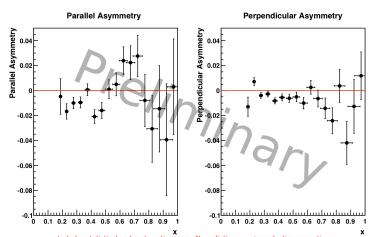
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Asymmetries (2)

E = 4.73 GeV Data: A_{\parallel} and A_{\perp}



Includes statistical and systematic errors. No radiative or pair-production corrections.

Figure: Asymmetry analysis by D. Parno and M. Posik. Plots from D. Parno's thesis.

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Asymmetries (3)

E = 4.73 GeV Data: $A_1^{^{3}{\rm He}}$

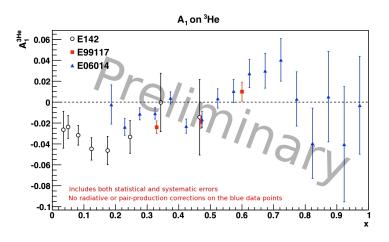


Figure: Asymmetry analysis by D. Parno and M. Posik. Plot from D. Parno's thesis.

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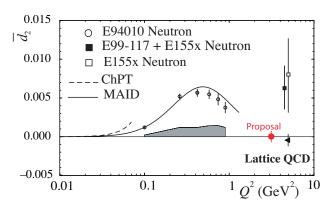
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Projected Error on d_2^n

Comparison to Current Data



- Projected statistical error: $\sim 5 \times 10^{-4}$
 - Four times better than current world average
 - Direct test of Lattice QCD

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- Interested in quark-gluon correlations
 - Exploit transverse spin interactions through the g_2 structure function, leading to higher twist effects seen in the matrix element d_2^n
 - Sheds light upon the Lorentz color force inside the nucleon
- Preliminary results for $A_1^{^3{
 m He}}$ are in good agreement with the JLab E99-117 result and provides more complete kinematic coverage with more data points and better statistics
- Our calculation of d_2^n will provide a benchmark test for Lattice QCD

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Current and Future Work

- Radiative corrections to the cross section and asymmetry data
- Computing the asymmetries for the second (E = 5.89 GeV) data set
- Extracting the asymmetry A_1^n , the spin structure functions $g_1^{^3{\rm He},n}$, $g_2^{^3{\rm He},n}$ and d_2^n

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 M. Posik, Y. Zhang, G. Franklin, Z.-E. Meziani
- This work is supported by: DOE Award from Temple University #DE-FG02-94ER40844.

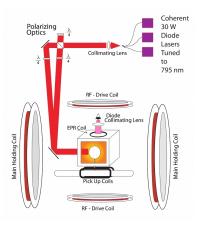
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Backup (1) 3 He Target



- Vaporized Rb is optically pumped using circularly polarized light to polarize its electrons
- Through hybrid spin-exchange the Rb electrons transfer their spin to K atoms, then K to ³He nuclei

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• The spin structure functions:

$$\begin{array}{lll} g_{1} & = & \frac{MQ^{2}}{4\alpha^{2}} \frac{2y}{(1-y)(2-y)} \sigma_{0} \left[A_{\parallel} + \tan \left(\theta/2 \right) A_{\perp} \right] \\ g_{2} & = & \frac{MQ^{2}}{4\alpha^{2}} \frac{y^{2}}{(1-y)(2-y)} \sigma_{0} \left[-A_{\parallel} + \frac{1+(1-y)\cos \theta}{(1-y)\sin \theta} A_{\perp} \right] \end{array}$$