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

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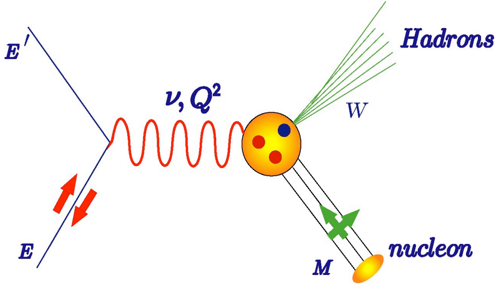
Outline

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

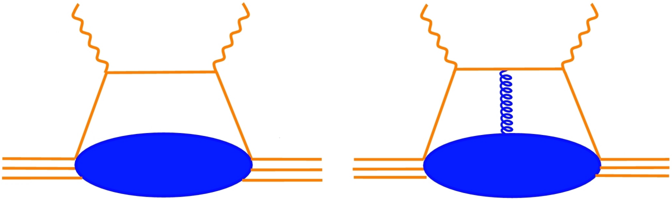
Quark-Gluon Correlations

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

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

- Seen in the imaginary part of virtual Compton scattering:



Leading Twist = Twist 2   Higher Twist = Twist 3

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

$$
\begin{aligned}
d_2^n\left(Q^2\right) &= \int_0^1 x^2\left[2g_1\left(x,Q^2\right)+3g_2\left(x,Q^2\right)\right]dx \\
&= 3\int_0^1 x^2\overline{g}_2\left(x,Q^2\right)dx
\end{aligned}
$$

- Gives a direct measure of twist-3 effects in the neutron at leading order

The Lorentz Color Force

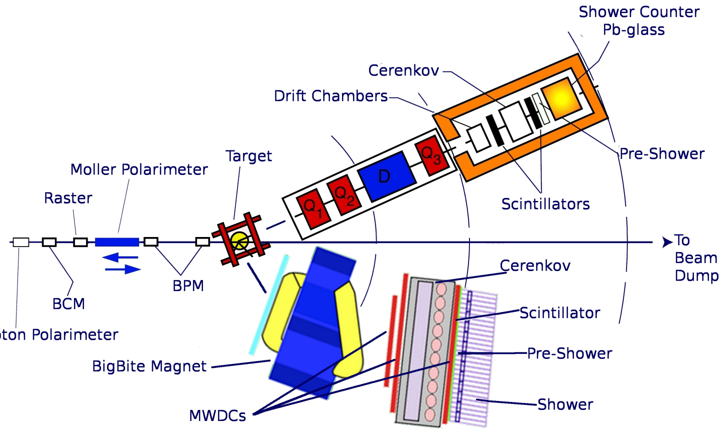
- $Q^2 > 1\ \mathrm{GeV}^2$ The expression for the transverse (color) force on the active quark right after it is struck by the virtual photon in the interaction reads:

$$\begin{aligned} F^y(0) &\equiv -\frac{\sqrt{2}}{2P^+}\langle P,S \mid \bar{\psi}_q(0)\, G^{+y}(0)\, \gamma^+ \psi_q(0) \mid P,S\rangle \\ &= -\frac{1}{2} M^2 d_2^n \end{aligned}$$

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

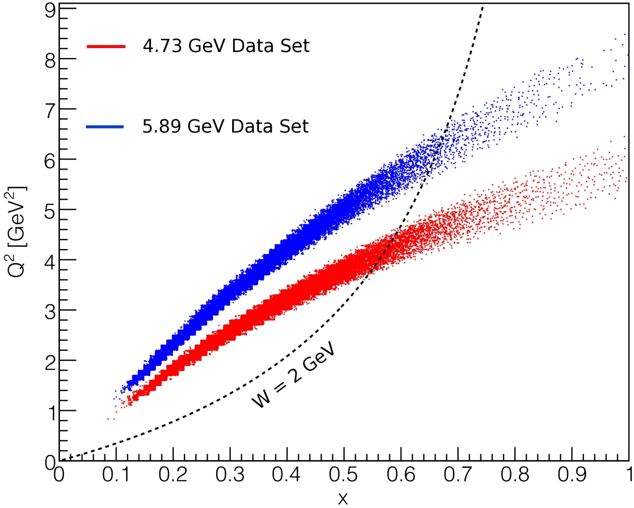
The E06-014 Experiment

Setup



The E06-014 Experiment

Kinematic Coverage



The E06-014 Experiment

Electron Beam Polarization

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

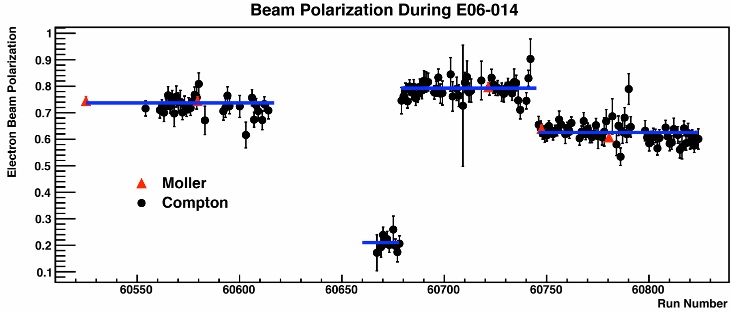


Figure: Compton data analysis by D. Parno. Plot from D. Parno's thesis.

The E06-014 Experiment

^{3}He Target Polarization

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

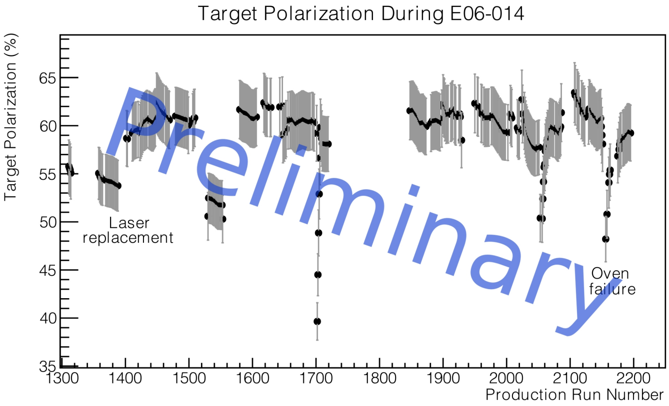


Figure: Target polarization analysis by Y. Zhang.

The Measurement of d_2^n

- Combine our measured cross-sections and asymmetries:

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

$$A_\parallel = \frac{\sigma^{\downarrow\Uparrow} - \sigma^{\uparrow\Uparrow}}{\sigma^{\downarrow\Uparrow} + \sigma^{\uparrow\Uparrow}} \quad A_\perp = \frac{\sigma^{\downarrow\Rightarrow} - \sigma^{\uparrow\Rightarrow}}{\sigma^{\downarrow\Rightarrow} + \sigma^{\uparrow\Rightarrow}} \quad \sigma_0 = \frac{N}{(Q/e)\rho L T \varepsilon} \frac{1}{w \Delta E' \Delta\Omega \Delta Z}$$

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

Cross Sections (1)

E = 4.73 GeV Data

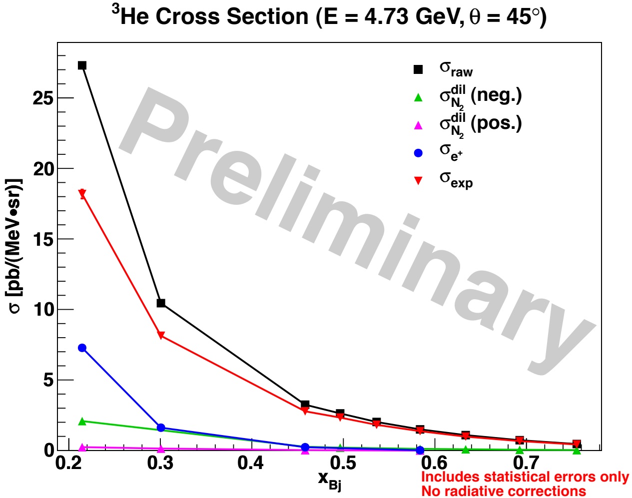


Figure: Cross section analysis by D. Flay.

Cross Sections (2)

E = 5.89 GeV Data

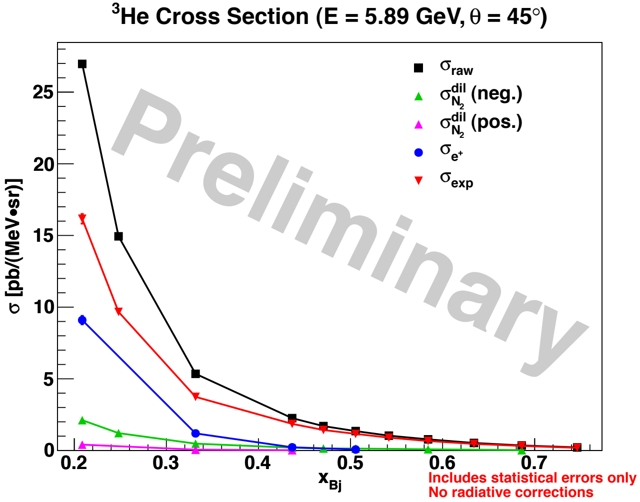


Figure: Cross section analysis by D. Flay.

Asymmetries (1)

A_1: The Virtual Photon-Nucleon Asymmetry

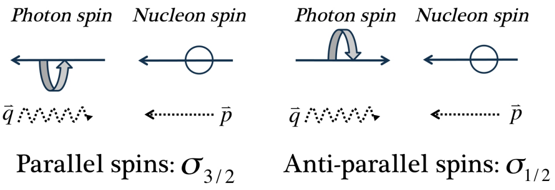


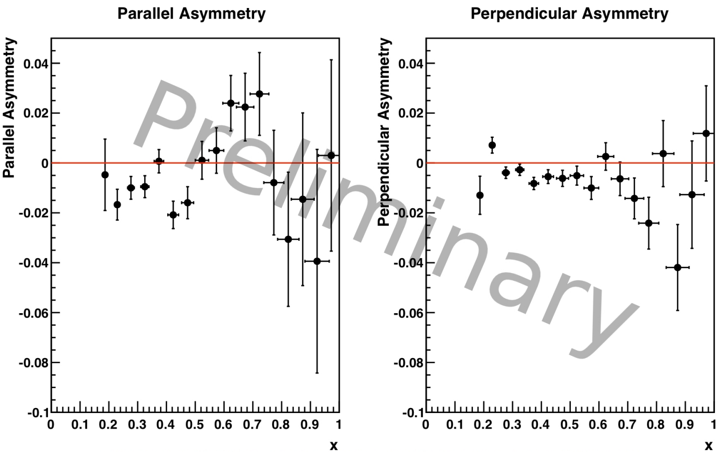
Figure: Reproduced from D. Parno's thesis.

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

$$\begin{aligned} A_1\left(x,Q^2\right) &\equiv \frac{\sigma_{1/2}-\sigma_{3/2}}{\sigma_{1/2}+\sigma_{3/2}} \\ &= \frac{g_1\left(x,Q^2\right)-\gamma^2 g_2\left(x,Q^2\right)}{F_1\left(x,Q^2\right)} \\ &= \frac{1}{D\left(1+\eta\xi\right)}A_{\parallel} - \frac{\eta}{d\left(1+\eta\xi\right)}A_{\perp} \end{aligned}$$

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.

Asymmetries (3)

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

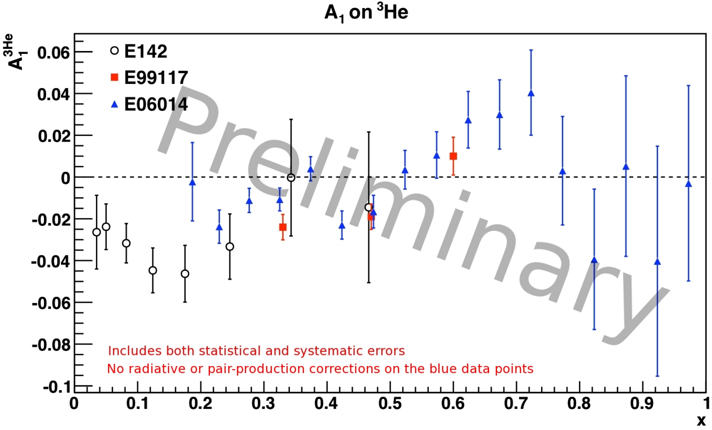
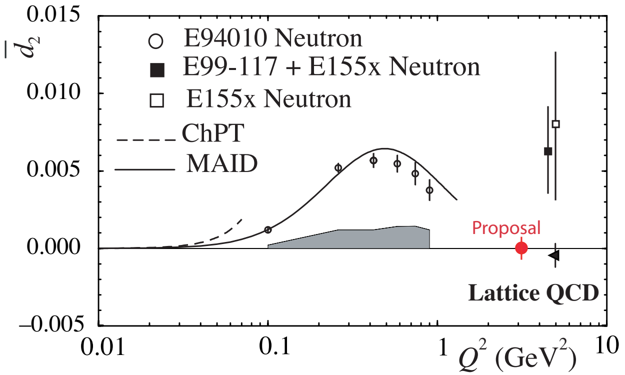


Figure: Asymmetry analysis by D. Parno and M. Posik. Plot from D. Parno's thesis.

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

Summary

- 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 $A_1^{^3\mathrm{He}}$ 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

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 $g_1^{^3\mathrm{He},n}$, $g_2^{^3\mathrm{He},n}$ and d_2^n

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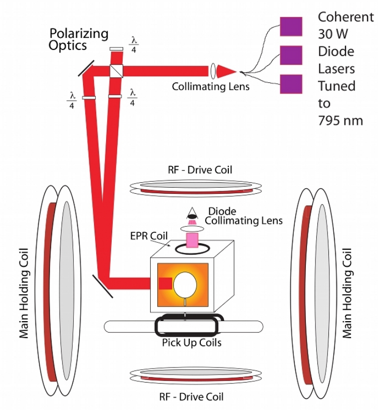
Backup (1)

^{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 ^{3}He nuclei

Backup (2)

Physics Measurements

- The spin structure functions:

$$g_1 = \frac{MQ^2}{4\alpha^2}\frac{2y}{(1-y)(2-y)}\sigma_0\left[A_{\parallel} + \tan(\theta/2)\,A_{\perp}\right]$$

$$g_2 = \frac{MQ^2}{4\alpha^2}\frac{y^2}{(1-y)(2-y)}\sigma_0\left[-A_{\parallel} + \frac{1+(1-y)\cos\theta}{(1-y)\sin\theta}A_{\perp}\right]$$