A Precision Measurement of d_2^n: Probing the Lorentz Color Force

A Status Report on Behalf of the E06-014 Collaboration

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Outline

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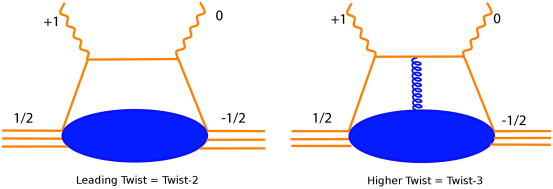
What is d_2^n? (1)

The Spin Structure Function g_2

- The g_2 spin structure function contains quark-gluon correlations
  - Its study could possibly yield a better understanding of the nature of confinement
  - It is written as: $g_2\left(x, Q^2\right) = g_2^{WW}\left(x, Q^2\right) + \bar{g}_2\left(x, Q^2\right)$
    - $g_2^{WW}\left(x, Q^2\right) = -g_1\left(x, Q^2\right) + \int_x^1 \frac{g_1\left(y, Q^2\right)}{y} dy$
    - $\bar{g}_2\left(x, Q^2\right) = -\int_x^1 \frac{1}{y}\frac{\partial}{\partial y}\left[\frac{m_q}{M} h_T\left(y, Q^2\right) + \xi\left(y, Q^2\right)\right] dy$



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Expressions of d_2^n (2)

d_2^n as a Second Moment of the Structure Functions

- d_2^n is expressed as the second moment of a linear combination of g_1 and g_2:

$$
\begin{aligned}
d_2^n\left(Q^2\right) &= \int_0^1 x^2\left[2g_1\left(x,Q^2\right)+3g_2\left(x,Q^2\right)\right]dx \\
&= 6\int_0^1 x^2\bar{g}_2\left(x,Q^2\right)dx
\end{aligned}
$$

- d_2^n is a direct measure of twist-3 effects in the neutron

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What is d_2^n? (3)

Operator Product Expansion, Color Polarizabilities

- Under Operator Product Expansion, d_2^n is given as the matrix element:

$$\begin{aligned} \langle P,S \mid \psi_q^\dagger \vec{\alpha} \times g\vec{E}\psi_q \mid P,S\rangle &= 2M^2\chi_E\vec{S}, \\ \langle P,S \mid \psi_q^\dagger g\vec{B}\psi_q \mid P,S\rangle &= 2M^2\chi_B\vec{S} \end{aligned}$$

$$\Rightarrow d_2^n = \frac{1}{8}\left(\chi_E + 2\chi_B\right)$$

  - At low Q^2, d_2^n ~~is seen as a color polarizability (X. Ji)~~
  - At high Q^2, d_2^n is more appropiately seen as a transverse color force

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

  - Therefore, d_2^n is a measure of this transverse Lorentz color force (M. Burkardt)

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Experimental Extraction (1)

Methodology and Kinematics

- A longitudinally polarized electron beam is scattered off of a ^{3}He target, polarized either transversely or longitudinally with respect to the beam
- Measure the unpolarized total cross section σ_0, and the longitudinal and perpendicular asymmetries $A_{\parallel}$, $A_{\perp}$, which allows for the determination of g_1, g_2 and subsequently d_2^n
- Kinematics – covers the resonance and deep inelastic quark regions:
  - $E = 4.73, 5.89$ GeV
  - $0.2 \leq x \leq 0.7$
  - $2 \leq Q^2 \leq 6$ GeV^2

Experimental Extraction (2)

Expressions of g_1, g_2, d_2^n

$$
\begin{aligned}
g_1 &= \frac{MQ^2}{4\alpha^2}\frac{2y}{(1-y)(2-y)}\sigma_0\left[A_{\parallel} + \tan(\theta/2)\,A_{\perp}\right] \\
g_2 &= \frac{MQ^2}{4\alpha^2}\frac{y^2}{(1-y)(2-y)}\sigma_0\left[-A_{\parallel} + \frac{1+(1-y)\cos\theta}{(1-y)\sin\theta}A_{\perp}\right] \\
d_2^n &= \int_0^1 \frac{MQ^2}{4\alpha^2}\frac{x^2y^2}{(1-y)(2-y)}\sigma_0 \\
&\times \left[\left(3\frac{1+(1-y)\cos\theta}{(1-y)\sin\theta} + \frac{4}{y}\tan(\theta/2)\right)A_{\perp} + \left(\frac{4}{y}-3\right)A_{\parallel}\right]dx
\end{aligned}
$$

$$
A_{\parallel} = \frac{\sigma^{\downarrow\Uparrow} - \sigma^{\uparrow\Uparrow}}{2\sigma_0} \quad A_{\perp} = \frac{\sigma^{\downarrow\Rightarrow} - \sigma^{\uparrow\Rightarrow}}{2\sigma_0}
$$

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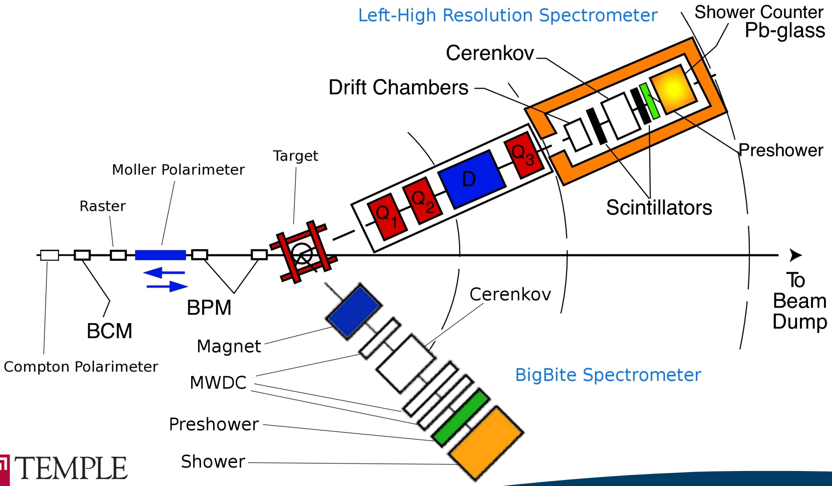
Experimental Setup (1)



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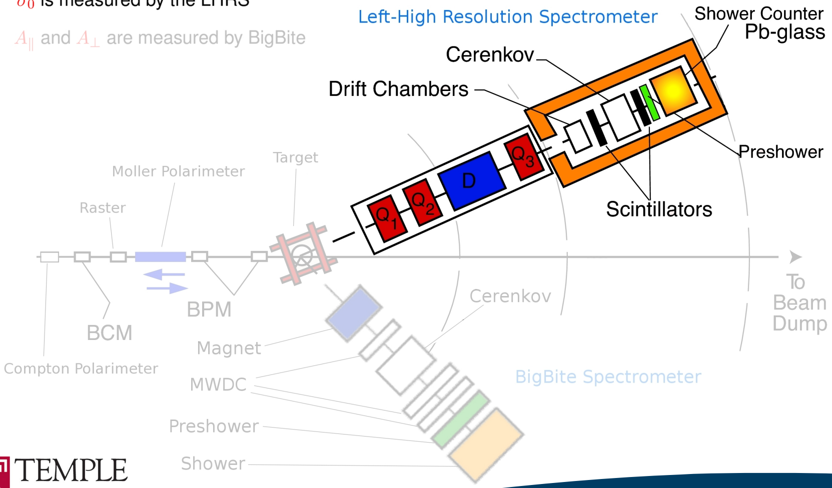
Experimental Setup (2)

σ_0 is measured by the LHRS

$A_\parallel$ and $A_\perp$ are measured by BigBite



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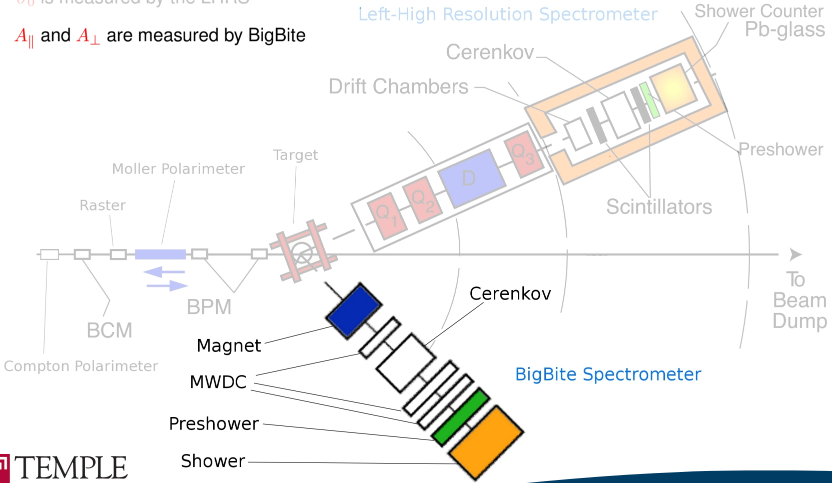
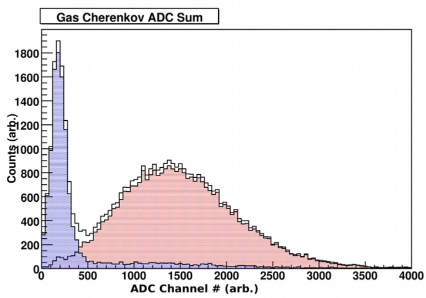
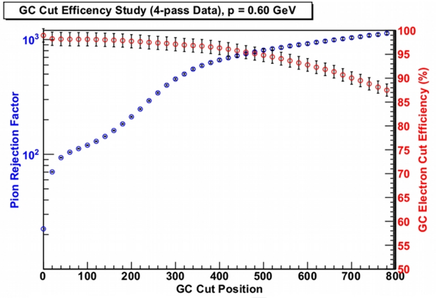


Analysis Update (1)

LHRS: Gas Čerenkov PID Study

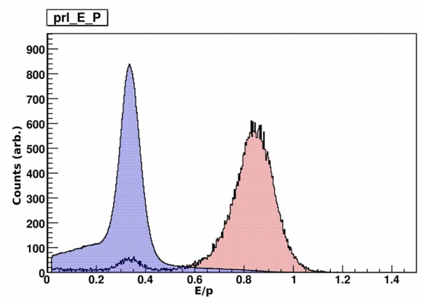


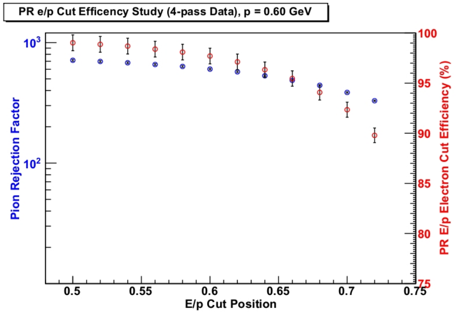


- Projected cut: ~ 300 Channels in the ADC (1.5 photoelectrons)
- Electron cut efficiency: $\sim 97\%$ for all kinematics
- Pion rejection factor: $\sim 10^2$

Analysis Update (2)

LHRS: Pion Rejector PID Study





- Projected cut: $E/p \sim 0.54$
- Electron cut efficiency: $\sim 99\%$ for all kinematics
- Pion rejection factor: $\sim 10^2$

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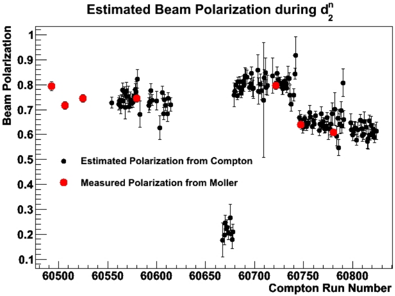
Analysis Update (3)

BigBite:

- BigBite Analysis

Analysis Update (4)
Compton: Beam Polarimetery



- Translation from asymmetry to polarization:
  - Measured photon polarization
  - Analyzing power computed using GEANT4 Monte Carlo
- Polarization measurements from both the Compton and Møller provide checks for one another

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What's Next?

- Detector Analyis:
  - LHRS: Currently checking the Optics
  - BigBite:
  - Compton: Still working on quantifying systematic errors, which we think will be at percent-level or below
- Work towards extraction of:
  - Statistical errors
  - Preliminary σ_0, $A_{\parallel}$, $A_{\perp}$

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