Measurement of Polarized Valence Quark Distribution Functions using Polarized Proton and Deuteron Targets

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Outline

• Motivation
• Physics
• Experimental Setup
• Prelim Results
• Conclusions
Motivation

- Semi-Inclusive Double Spin Asymmetry Measurement
- Extraction of $(\Delta d/d)$ observable
- The perturbative Quantum Chromodynamics (pQCD) vs the hyperfine perturbed Constituent Quark Model (CQM)
The Standard Model

- The theory of the three fundamental interactions
- Three kinds of elementary particles
- 12 – leptons, 36 – quarks, 4 – force mediators

<table>
<thead>
<tr>
<th>Quarks</th>
<th>Leptons</th>
<th>Bosons (Forces)</th>
</tr>
</thead>
<tbody>
<tr>
<td>mass</td>
<td>charge</td>
<td>spin</td>
</tr>
<tr>
<td>2.4 MeV</td>
<td>$\frac{2}{3}$</td>
<td>$\frac{1}{2}$</td>
</tr>
<tr>
<td>1.27 GeV</td>
<td>$\frac{2}{3}$</td>
<td>$\frac{1}{2}$</td>
</tr>
<tr>
<td>171.2 GeV</td>
<td>$\frac{2}{3}$</td>
<td>$\frac{1}{2}$</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>
Quantum Chromodynamics vs Constituent Quark Model

- Valence, sea quarks and gluons
- Asymptotic Freedom
- Confinement

- Baryon – qqq
- Meson – quark-antiquark
- Quark confinement

http://www.jlab.org/highlights/phys.html
Deep Inelastic Scattering vs $Q^2$

$Q^2$ - Four Momentum Transferred Squared, $d=(0.2\text{GeV} \times \text{fm})/Q$
Valence Quark Region

\( X_{bj} > 0.3 \)
Semi Inclusive Deep Inelastic Scattering (SIDIS) Diagram

\[ \frac{d^3 \sigma_{1/2(3/2)}^h}{dxdQ^2 dz} \approx \sum_q e_q^2 q^{+(-)}(x, Q^2) D_q^h(z, Q^2) \]
Semi Inclusive Double Spin Asymmetry

\[ A_1^h = \frac{\sigma_{1/2}^h - \sigma_{3/2}^h}{\sigma_{1/2}^h + \sigma_{3/2}^h} \]

\[ A_{1,p}^{\pi^+\pi^-} = \frac{4\Delta u_v(x) \pm \Delta d_v(x)}{4u_v(x) \pm d_v(x)} \]

\[ A_{1,2H}^{\pi^+\pi^-} = \frac{\Delta u_v(x) + \Delta d_v(x)}{u_v(x) + d_v(x)} \]

Semi Inclusive deep inelastic scattering provides and opportunity to determine the struck quark flavor.
Polarized and Unpolarized Structure Functions

Asymmetry

Unpolarized structure function

Polarized structure function

\[ A(x, Q^2) = \frac{g_1(x)}{F_1(x)} \]

\[ F_1(x) = M_h W_1 = \frac{1}{2} \sum q^2 q(x) \]

\[ g_1(x) = \frac{1}{2} \sum q^2 (q^+(x) - q^-(x)) = \frac{1}{2} \sum q^2 \Delta q(x) \]
- Polarized electron beam
- Polarized targets
- Superconducting toroid magnet
- Drift chambers
- Cherenkov counter
- Electromagnetic calorimeter
Target Materials

- Frozen ammonia: the polarized proton and neutron
- For background elimination: C12, liquid Helium and Nitrogen
- Polarized using the Dynamic Nuclear Polarization (DNP) Method
- ~96% and ~46% polarization for the proton and neutron targets

Drift Chambers

- The trajectory of the charged particle
- Three regions
- ArCO₂ (90/10%) - gas mixture
- The drift time and drift velocity
Cherenkov Detector

- The threshold detector
- Differentiate electrons from pions
- Gas – C4F10 (n=1.00153, high photon yield)
- Thresholds: 9 MeV for electrons and 2.5 GeV for pions
The CLAS TOF Scintillators

- 288 scintillators
- The time of flight for charged particle
- Coincidence for charged particles
- 120ps – 250ps time resolution
- 30 cm to 450 cm long
The CLAS Calorimeter

- 8 electromagnetic calorimeter modules
- Measures the total energy deposited by the crossing particle
- Neutron detection
- Electron detection above 0.5 GeV
- Photon detection above 0.2 GeV
Kinematics of single pion electroproduction

- The virtual photon negative four-momentum transferred squared
- Invariant mass of the photon-nucleon system
- The polar angle of the outgoing pion in CMF
- The azimuthal angle of the outgoing pion in CMF
- The scattered electron angle
Particle Identification Using Electromagnetic calorimeter

Cuts on the energy deposited in the electromagnetic calorimeter (ECtotal>0.2*p and ECinner>0.06*p)
The pion contamination in electron sample is ~ 9.6 %, and for NPHE > 2.5 ~ 4.03 %
Data Comparison

\( \varphi_{\pi^*} \) vs Relative rate for fixed \( \cos \theta_{pion}^{CM} = 0.5 \) and \( W = 1.45 \text{GeV} \)
The Expected Precision of This Analysis

The ratio of polarized to unpolarized valence down quark distribution function vs $X_{Bj}$
Future Plans

- Measure asymmetries using the knowledge of the probe and target's polarization state
- The double spin asymmetries
- About three data points will be extracted from this analysis