Parity Violation in DIS at 12 GeV

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Outline

• Physics potential
  – Standard Model Test
  – Charge Symmetry Violation (CSV)
  – Higher Twist
  – d/u for the Proton
• New Solenoidal Spectrometer (SoLID)
• Polarimetry
PV Asymmetries: Any Target and Any Scattering Angle

\[ -A_{LR} = A_{PV} = \frac{\sigma^- - \sigma^+}{\sigma^- + \sigma^+} \sim \frac{A_{\text{weak}}}{A_{\gamma}} \sim \frac{G_F Q^2}{4 \pi \alpha} (g_A^e g_V^T + \beta g_V^e g_A^T) \]

- The couplings \( g^T \) depend on electroweak physics as well as on the weak vector and axial-vector hadronic current.
- For PVDIS, both new physics at high energy scales as well as interesting features of hadronic structure come into play.
- A program with a broad kinematic range can untangle the physics.
PVDIS: Electron-Quark Scattering

Many new physics models give rise to neutral ‘contact’ (4-Fermi) interactions:
Heavy Z’s, compositeness, extra dimensions…

Four Couplings arise in PV in $e^-$-hadron scattering

\[
\begin{align*}
C_{1i} &= 2g_A^i g_V^e \\
C_{2i} &= 2g_V^i g_A^e
\end{align*}
\]

\[
\begin{align*}
C_{1u} &= -\frac{1}{2} + \frac{4}{3} \sin^2 (\theta_W) + \delta C_{1u} \approx -0.19 \\
C_{1d} &= \frac{1}{2} - \frac{2}{3} \sin^2 (\theta_W) + \delta C_{1d} \approx 0.35 \\
C_{2u} &= -\frac{1}{2} + 2 \sin^2 (\theta_W) + \delta C_{2u} \approx -0.030 \\
C_{2d} &= \frac{1}{2} - 2 \sin^2 (\theta_W) + \delta C_{2d} \approx 0.025
\end{align*}
\]

$C_{1u}$ and $C_{1d}$ will be determined to high precision by $Q_{\text{weak}}$, APV Cs

$C_{2u}$ and $C_{2d}$ are small and poorly known:
one combination can be accessed in PV DIS
Deep Inelastic Scattering

For an isoscalar target like $^2\text{H}$, structure functions largely cancel in the ratio at high $x$.

At high $x$, $A_{PV}$ becomes independent of $x$, $W$, with well-defined SM prediction as a function of $Q^2$ and $y$.

PVDIS: Only way to measure $C_{2q}$

Unknown radiative corrections for coherent processes
Sensitivity: $C_1$ and $C_2$ Plots

Precision Data
Selected Electroweak Data

Evidence for unexpected hadronic physics?

1. $s \neq \bar{s}$
2. Nucleon CSV
3. Nuclear CSV
Search for CSV in PV DIS

\[ u^p(x) = d^n(x) ? \]
\[ d^p(x) = u^n(x) ? \]

- \text{u-d mass difference} \quad \delta u(x) = u^p(x) - d^n(x)
- \text{electromagnetic effects} \quad \delta d(x) = d^p(x) - u^n(x)

- \text{Direct observation of parton-level CSV would be very exciting!}
- \text{Important implications for high energy collider pdfs}
- \text{Could explain significant portion of the NuTeV anomaly}

For \( A_{PV} \) in electron-\(^2\)H DIS:

\[ \frac{\delta A_{PV}}{A_{PV}} = 0.28 \frac{\delta u - \delta d}{u + d} \]

\text{Sensitivity will be further enhanced if} \( u+d \) \text{ falls off more rapidly than} \( \delta u - \delta d \) \text{ as} \( x \to 1 \)
Sensitivity with PVDIS

\[ R_{CSV} = \frac{\delta A_{PV}(x)}{A_{PV}(x)} = 0.28 \frac{\delta u(x) - \delta d(x)}{u(x) + d(x)} \]
Higher Twist

- $A_{PV}$ sensitive to diquarks: ratio of weak to electromagnetic charge depends on amount of coherence (elastic He vs PVDIS)
- Do diquarks have twice the $x$ of single quarks?
- If Spin 0 diquarks dominate, likely only $1/Q^4$ effects
Why HT in PVDIS is Special

Start with Lorentz Invariance (No PDF’s)

\[ A \propto \frac{l_{\mu\nu} \int \langle D | j^\mu(x)J^\nu(0) + J^\mu(x)j^\nu(0) | D \rangle e^{iq \cdot x} d^4x}{l_{\mu\nu} \int \langle D | j^\mu(x)j^\nu(0) | D \rangle e^{iq \cdot x} d^4x} \]

\[ V_\mu = \left( u_\gamma u - \bar{d}_\gamma d \right) \implies S_\mu = \left( u_\gamma u + \bar{d}_\gamma d \right) \]

\[ \langle VV \rangle = l_{\mu\nu} \int \langle D | V^\mu(x)V^\nu(0) | D \rangle e^{iq \cdot x} d^4x \]

Next use CVC (Works only for deuteron)

\[ A = \frac{(C_{1u} - C_{1d})\langle VV \rangle + \frac{1}{3}(C_{1u} + C_{1d})\langle SS \rangle}{\langle VV \rangle + \frac{1}{3}\langle SS \rangle} \]

Zero in QPM

HT in \( F_2 \) is probably dominated by quark-gluon correlations

\[ \langle VV \rangle - \langle SS \rangle = \langle (V - S)(V + S) \rangle \propto l_{\mu\nu} \int \langle D | \bar{u}(x)\gamma^\mu u(x)\bar{d}(0)\gamma^\nu d(0) | D \rangle e^{iq \cdot x} d^4x \]

Vector-hadronic piece only

Higher-Twist valance quark-quark correlations is only non-scaling physics
Quark-Quark vs Quark-Gluon

PVDIS is the only known way to isolate quark-quark correlations.

FIG. 3. The only gluon operator that we keep is the operator $O^g$, which can be expressed as a four-quark operator using the equations of motion.

Quark-gluon operators correspond to transverse momentum.
Statistical Errors (%) vs Kinematics

**Strategy:** sub-1% precision over broad kinematic range for sensitive Standard Model test and detailed study of hadronic structure contributions

Error bar $\sigma_{A/A}$ (%) shown at center of bins in $Q^2$, $x$

- 4 months at 11 GeV
- 2 months at 6.6 GeV
Coherent Program of PVDIS Study

Strategy: requires precise kinematics and broad range

Fit data to:

\[ A = A \left[ 1 + \beta_{HT} \frac{1}{(1-x)^3 Q^2} + \beta_{CSV} x^2 \right] \]

\[ C(x) = \beta_{HT}/(1-x)^3 \]

- Measure \( A_D \) in NARROW bins of \( x, Q^2 \) with 0.5% precision
- Cover broad \( Q^2 \) range for \( x \) in \([0.3, 0.6]\) to constrain \( HT \)
- Search for CSV with \( x \) dependence of \( A_D \) at high \( x \)
- Use \( x>0.4, \) high \( Q^2, \) and \( \) to measure a combination of the \( C_{iq} 's \)

<table>
<thead>
<tr>
<th></th>
<th>( x )</th>
<th>( y )</th>
<th>( Q^2 )</th>
</tr>
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<tbody>
<tr>
<td>New Physics</td>
<td>no</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>CSV</td>
<td>yes</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>Higher Twist</td>
<td>yes</td>
<td>no</td>
<td>yes</td>
</tr>
</tbody>
</table>
PVDIS on the Proton: d/u at High x

\[ a^P(x) \approx \frac{u(x) + 0.91d(x)}{u(x) + 0.25d(x)} \]

Deuteron analysis has large nuclear corrections (Yellow)

A_{PV} for the proton has no such corrections (complementary to BONUS)

The challenge is to get statistical and systematic errors \( \sim 2\% \)

July 25, 2010

PVDIS with at 12 GeV
CSV in Heavy Nuclei: EMC Effect

Additional possible application of SoLID

Isovector-vector mean field. (Cloet, Bentz, and Thomas)
SoLID Spectrometer

Babar Solenoid
Gas Cerenkov
Shashlyk Calorimeter
Baffles
GEM’s

ANL design
## Error Budget in %

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
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<tbody>
<tr>
<td>Statistics</td>
<td>0.3</td>
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<tr>
<td>Polarimetry</td>
<td>0.4</td>
</tr>
<tr>
<td>Q2</td>
<td>0.2</td>
</tr>
<tr>
<td>Radiative Corrections</td>
<td>0.3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>0.6</strong></td>
</tr>
</tbody>
</table>
Atomic Hydrogen For Moller Target

Moller polarimetry from polarized atomic hydrogen gas, stored in an ultra-cold magnetic trap

- Tiny error on polarization
- Thin target (sufficient rates but no dead time)
- 100% electron polarization
- Non-invasive
- High beam currents allowed
- No Levchuk effect

10 cm, $\rho = 3 \times 10^{15}$/cm$^3$
in B = 7 T at T=300 mK

$$\frac{n_+}{n_-} = e^{-2\mu B / kT} \approx 10^{-14}$$

Brute force polarization

High Precision Compton

At high energies, SLD achieved 0.5%.
Why do we think we can do better?

- SLD polarimeter near interaction region - background heavy
- No photon calorimeter for production
- Hall A has “counting” mode (CW)
- Efficiency studies
- Tagged photon beam
- Greater electron detector resolution

- Small asymmetries
  = long time to precision
  = cross-checks are difficult
- Zero-crossing technique is new. (zero crossing gets hard near the beam)
- Photon calorimetry is harder at small $E_\gamma$
PVDis Collaboration


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PVDis with at 12 GeV 21

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Summary

• The physics is varied and exciting.
  – Excellent sensitivity to $C_{2u}$ and $C_{2d}$.
  – Test CSV at quark level.
  – Unique window on higher twists.

• We will build a novel apparatus (with many other possible applications, eg. SIDIS)
Higher Twist Fit to $\nu$ Data

**FIGURE 2.** Left figure: the $1\sigma$ error bands for the high-twist terms in the isospin-symmetric combinations of different structure functions (solid lines: $F_2$, dashes: $F_T$, dots: $F_L$) for charged leptons. Right figure: corresponding $1\sigma$ bands for neutrino scattering off an isoscalar target (upper panel: $F_2$, lower panel: $xF_3$). The predictions for $F_2$ from charged leptons rescaled by the corresponding leading twist terms are also shown for comparison.

Analysis of Alekhin, Kulagin, and Petti
Layout of Spectrometer using CDF coil

- Coil mounting is well understood from CDF
  - Designed to be supported by end
  - Supports allow radial movement in both ends for thermal
  - One end fixed axially
- Will need to check for decentering forces due to field asymmetry (Lorentz forces)
Error Projections for Moller Polarimetry

<table>
<thead>
<tr>
<th>Variable</th>
<th>Hall C</th>
<th>Hall A</th>
<th>Hall A</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fe at 3T</td>
<td>H1 gas</td>
<td></td>
</tr>
<tr>
<td>Target polarization</td>
<td>0.25%</td>
<td>0.50%</td>
<td>0.25%</td>
</tr>
<tr>
<td>Target angle</td>
<td>0.00%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Analyzing power</td>
<td>0.24%</td>
<td>0.30%</td>
<td>0.20%</td>
</tr>
<tr>
<td>Levchuk effect</td>
<td>0.30%</td>
<td>0.20%</td>
<td>0.20%</td>
</tr>
<tr>
<td>Target temperature</td>
<td>0.05%</td>
<td>0.02%</td>
<td>0.02%</td>
</tr>
<tr>
<td>Dead time</td>
<td>-</td>
<td>0.30%</td>
<td>0.15%</td>
</tr>
<tr>
<td>Background</td>
<td>-</td>
<td>0.30%</td>
<td>0.15%</td>
</tr>
<tr>
<td>Others</td>
<td>0.10%</td>
<td>0.30%</td>
<td>0.15%</td>
</tr>
<tr>
<td>Beam extrapolation</td>
<td>?</td>
<td>0.15%</td>
<td>0.15%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>0.47%</strong></td>
<td><strong>0.82%</strong></td>
<td><strong>0.48%</strong></td>
</tr>
</tbody>
</table>

Table from MOLLER director’s review by E. Chudakov
Summary of Compton Uncertainties

<table>
<thead>
<tr>
<th>Relative Error (%)</th>
<th>electron</th>
<th>photon</th>
</tr>
</thead>
<tbody>
<tr>
<td>E_{beam}</td>
<td>0.03</td>
<td>0.03</td>
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<tr>
<td>Laser Polarization</td>
<td>0.20</td>
<td>0.20</td>
</tr>
<tr>
<td>Radiative Corrections</td>
<td>0.1</td>
<td>0.1</td>
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<tr>
<td>False Asymmetries</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>Background</td>
<td>0.05</td>
<td>0.05</td>
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<tr>
<td>Deadtime / Pileup</td>
<td>0.2</td>
<td>0.1</td>
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<tr>
<td>Analyzing power</td>
<td>0.15</td>
<td>0.40</td>
</tr>
<tr>
<td>Total</td>
<td>0.34</td>
<td>0.47</td>
</tr>
</tbody>
</table>

Independent detection of photons and electrons provides two (nearly) independent polarization measurements; each should be better than 0.5%.

This would represent a significant step beyond what has been done at JLab before, but there is no fundamental reason why it should not be achievable.

Participants from UVa, Syracuse, JLab, CMU, ANL, Miss. St.
Need Full Phenomenology

\[
\left[ \frac{d^2 \sigma}{dx dy} \right]_{EM} \propto 2xyF_1^\gamma + \frac{2}{y} (1 - y - \frac{xyM}{2E})F_2^\gamma
\]

\[
\left[ \frac{d^2 \sigma}{dx dy} \right]_{\gamma Z}^V \propto \frac{G}{2\sqrt{2\pi\alpha}} \left[ -g_A \{ 2xyF_1^{\gamma Z} + \frac{2}{y} (1 - y - \frac{xyM}{2E})F_2^{\gamma Z} \} \right]
\]

\[
\left[ \frac{d^2 \sigma}{dx dy} \right]_{\gamma Z}^A \propto \frac{G}{2\sqrt{2\pi\alpha}} \left[ -g_V x (2 - y)F_3^{\gamma Z} \right]
\]

There are 5 relevant structure functions

\[ A_B^{PV} = \frac{\sigma_{\gamma Z}^V + \sigma_{\gamma Z}^A}{\sigma_{EM}} \]

\[ a(x) = \frac{\sigma_{\gamma Z}^V}{\sigma_{EM}} \]

\[ f(y)b(x) = \frac{\sigma_{\gamma Z}^A}{\sigma_{EM}} \]

Small; use $\nu$ data (Higher twist workshop at Madison, Wisconsin)

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PVDIS with at 12 GeV
SoLiD Spectrometer

Solenoidal detector for PVDIS at high x

Yoke

Coil

LH target

Gas Cerenkov

Shashlyk

Baffles

GEM’s
Access to the Detectors

- End Cap rolls backward along the beam line on Hilman Rollers
- 342 metric tons for both end caps with baffles installed
- Must allow for 5% rolling resistance
Baffle geometry and support

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PVDIS with at 12 GeV