Measurement of Deuteron PVDIS Asymmetry at 6 GeV

Xiaochao Zheng
University of Virginia
January 2008

- The Physics of PVDIS, including:
  - Updates on hadronic effects
  - Update on knowledge of $C_{1q}$ and $C_{2q}$
- Experimental Setup and Data Analysis
- Expected Results and Uncertainties
- Beam Time Request and Summary

PR08-011 (E05-007 Update)
The Collaboration


The Hall A Collaboration

ANL, Calstate, FIU, JLab, Kentucky, Louisiana Tech, U. of Ljubljana (Slovenia), MIT, UMD, UMass, UNH, Universidad Nacional Autonoma de Mexico, Ohio U., Randolph-Mason C., Smith C., Syracuse, Temple U., UVa, W&M, Yerevan Phys. Inst. (Armenia)
The Physics of PVDIS at 6 GeV (E05-007)

- Measure PVDIS asymmetry on a deuterium target, $A_{d'}$, at $Q^2=1.10$ and 1.90 GeV$^2$ to 2% (stat.);
- From $Q^2=1.10$ can help to investigate if there are significant HT effects;
  — “Baseline” measurement for the future 12 GeV program.
- If HT is small, from $Q^2=1.90$ GeV$^2$ can extract $2C_{2u}-C_{2d}$ to ±0.033, a factor of 7.4 improvement;
- Total request 46 days, with 13 days approved (A-), $\Delta(2C_{2u}-C_{2d})=\pm0.066$.

PAC27 report: “The PAC recommends the approval of the first phase (13 days) ….. It will also allow extremely useful preparation for a second phase of the experiment which can be presented in the future.”

PAC33: requesting again for the full beam time (now 50 days).
Deuterium:

\[ A_d = (540 \text{ ppm}) Q^2 \frac{2C_{1u} [1 + R_C(x)] - C_{1d} [1 + R_S(x)] + Y (2C_{2u} - C_{2d}) R_V(x)}{5 + R_S(x) + 4R_C(x)} \]

\[ C_{1u} = g_A^e g_V^u = \frac{-1}{2} + \frac{4}{3} \sin^2(\theta_W) \]
\[ C_{1d} = g_A^e g_V^d = \frac{1}{2} - \frac{2}{3} \sin^2(\theta_W) \]
\[ C_{2u} = g_V^e g_A^u = -\frac{1}{2} + 2 \sin^2(\theta_W) \]
\[ C_{2d} = g_V^e g_A^d = \frac{1}{2} - 2 \sin^2(\theta_W) \]

Can extract \( C_{1,2q} \) (and \( \sin^2\theta_W \))

In the SM, tree level
PVDIS Asymmetries

\[ A_{PV} = \frac{2 C_{1u} [1 + R_C (x)] - C_{1d} [1 + R_S (x)] + Y (2 C_{2u} - C_{2d}) R_V (x)}{5 + R_S (x) + 4 R_C (x)} \]

- Deuterium:
  \[ A_d = (540 \text{ ppm}) Q^2 \]
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  \[ C_{2d} = g_V^d g_A^d = \frac{1}{2} - 2 \sin^2 (\theta_W) \]

- Can extract \( C_{1,2q} \) (and \( \sin^2 \theta_W \)) – discover new physics beyond the SM

- Sensitive to: Z' searches, compositeness, leptoquarks

- Mass limit:
  \[ \frac{\Lambda}{g} \approx \frac{1}{\sqrt{8 G_F \Delta (2C_{2u} - C_{2d})^{1/2}}} \approx 1.0 \text{ TeV} \]
PVDIS Asymmetries

\[ A_{PV} = \frac{2 C_{1u} [1 + R_C(x)] - C_{1d} [1 + R_S(x)] + Y (2 C_{2u} - C_{2d}) R_V(x)}{5 + R_S(x) + 4 R_C(x)} \]

Deuterium:

\[ A_d = (540 \text{ ppm}) Q^2 \frac{2 [s(x) + \bar{s}(x)]}{u(x) + \bar{u}(x) + d(x) + \bar{d}(x)} \quad R_S(x) = \frac{2 [c(x) + \bar{c}(x)]}{u(x) + \bar{u}(x) + d(x) + \bar{d}(x)} \quad R_C(x) = \frac{u_V(x) + d_V(x)}{u(x) + \bar{u}(x) + d(x) + \bar{d}(x)} \]

Also sensitive to:

- Non-perturbative QCD (higher-twist) effects
  - Small, but need confirmation
- Charge symmetry violation
  - Small from MRST fit (90% CL), negligible compared to 2%
PVDIS Experiment – Past, Present and Future


- PVDIS asymmetry has the potential to explore new physics, study hadronic effects/CSV ...... However, hasn’t been done since 1978.

- If we observe a significant deviation from the SM value, it will definitely indicate something exciting;

- At higher precision, separation of the three (new physics, HT, CSV) requires a larger PVDIS program at 11 GeV; PVDIS at 6 GeV will serve as the first step, and could possibly make an impact on electroweak SM study already.
# Current Knowledge on Weak Coupling Coefficients

<table>
<thead>
<tr>
<th>Facility</th>
<th>Process</th>
<th>$Q^2$</th>
<th>$C_{iq}$ Combination</th>
<th>Result</th>
<th>SM Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SLAC</td>
<td>$e^-D$ DIS</td>
<td>1.39</td>
<td>$2C_{1u}-C_{1d}$</td>
<td>-0.90± 0.17</td>
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<td>$0.66(2C_{2u}-C_{2d})+2C_{3u}-C_{3d}$</td>
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<td>MAINZ</td>
<td>$e^-Be$ QE</td>
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<td>$2.68C_{1u}-0.64C_{1d}+2.16C_{2u}-2C_{2d}$</td>
<td>-0.94± 0.21</td>
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</tr>
<tr>
<td>Bates</td>
<td>$e^-C$ elastic</td>
<td>0.0225</td>
<td>$C_{1u}+C_{1d}$</td>
<td>0.138±0.034</td>
<td>0.1528</td>
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<td>Bates</td>
<td>$e^-D$ QE</td>
<td>0.1</td>
<td>$C_{2u}-C_{2d}$</td>
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<td>-0.0624</td>
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<tr>
<td>Bates</td>
<td>$e^-D$ QE</td>
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<td>$2C_{1u}+C_{1d}$</td>
<td>approved</td>
<td>-0.0357</td>
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<tr>
<td>$^{133}$Cs APV</td>
<td>0</td>
<td></td>
<td>$-376C_{1u}-422C_{1d}$</td>
<td>-72.69±0.48</td>
<td>-73.16</td>
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<td>$^{205}$TI APV</td>
<td>0</td>
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<td>$-572C_{1u}-658C_{1d}$</td>
<td>-116.6±3.7</td>
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</tr>
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\[ C_{3q} = g^{e}A g^{q}A \]

PDG2002:  
$\Delta(2C_{2u}-C_{2d})=\pm0.24$  
(PAC27)  


X. Zheng, PAC33, January 2008
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<td></td>
</tr>
<tr>
<td>(^{205}\text{Pb}) APV</td>
<td>0</td>
<td>(-572C_{1u} - 658C_{1d})</td>
<td>-116.6 ± 3.7</td>
<td>-116.8</td>
<td></td>
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<tr>
<td>Fit</td>
<td>(e^-A) low</td>
<td></td>
<td>(C_{1u} + C_{1d})</td>
<td>0.1358 ± 0.0326</td>
<td>0.1528</td>
</tr>
<tr>
<td>All</td>
<td></td>
<td></td>
<td>(C_{1u} - C_{1d})</td>
<td>-0.4659 ± 0.0835</td>
<td>-0.5297</td>
</tr>
<tr>
<td>PVES</td>
<td>(\text{correlation} = -0.295)</td>
<td></td>
<td>(2C_{2u} - C_{2d})</td>
<td>±0.271</td>
<td></td>
</tr>
<tr>
<td>Data</td>
<td>(\Delta(2C_{2u} - C_{2d}) = ±0.24)</td>
<td></td>
<td>(C_{2u} + C_{2d})</td>
<td>-0.2063 ± 0.5659</td>
<td>-0.0095</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(C_{2u} - C_{2d})</td>
<td>-0.0762 ± 0.0437</td>
<td>-0.0621</td>
</tr>
</tbody>
</table>

**PDG2002:** \(\Delta(2C_{2u} - C_{2d}) = ±0.24\)  
(PAC27)

Current Knowledge on $C_{1,2q}$ (new)

- PDG best fit
- R. Young (combined)
- Cs APV
- R. Young (PVES)
- Qweak (expected)
- MIT/Bates
- SLAC/Prescott

Best: PDG2002 $\Delta(2C_{2u} - C_{2d}) = 0.24 \rightarrow$ factor of 7.4 improvement (same as PR05-007);

New physics mass limit: 1.0 TeV. (used 0.19 and "factor of 6", should be updated)
Current Knowledge on $C_{1,2q}$ (new)

- **PDG best fit**
- **R. Young (combined)**
- **Cs APV**
- **R. Young (PVES)**
- **Qweak (expected)**
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- **SAMPLE**
- **PDG 2006 fit**
- **SLAC/ Prescott**
- **This proposal (PDG fit)**
- **This proposal (R. Young’s fit)**

**Best:** PDG2002 $\Delta(2C_{2u}-C_{2d}) = 0.24 \rightarrow$ factor of 7.4 improvement (same as PR05-007);

New physics mass limit: 1.0 TeV. (used 0.19 and “factor of 6” in, should be updated)
PV DIS and Other SM Test Experiments

- **E158/Moller (SLAC)**
  - Coherent Quarks in the Nucleus
  - Purely leptonic

- **Atomic PV**
  - Coherent Quarks in the Nucleus
  - Purely leptonic

- **NuTeV (FNAL)**
  - Weak CC and NC difference
  - Nuclear structure?
  - Other hadronic effects?

- **Qweak (JLab)**
  - Coherent quarks in the proton
  - $2 (2C_{1u} + C_{1d})$

- **PVDIS (JLab)**
  - Isoscalar quark scattering
  - $(2C_{1u} - C_{1d}) + Y(2C_{2u} - C_{2d})$

**Different Experiments**
- **Probe Different Parts of Lagrangian,**
- **PVDIS is the only one accessing $C_{2q}$**

Cartoons borrowed from R. Arnold (UMass)
Status of Higher Twist Effects (HT)

- MRST: HT effect on $F_2 < 0.1\%$ for $0.1 < x < 0.3$ in NNLO and NNNLO;
  

- HT on PV calculations:
  
  - MIT Bag Model I: $0.3\%/Q^2$
  
  - MIT Bag Model II: $<2\%/Q^2$
  
  - Calculation using $C_{HT}$ from $F_2$ data ($F_2 = (F_2^{LT}(1+C_{HT}/Q^2))$: $<1%/Q^2$ for $0.1 < x < 0.3$

  - HT likely to be small at $Q^2 = 2\ (GeV/c)^2$, nevertheless, will measure $A_d$ at $1.1\ (GeV/c)^2$ to check

  - More up-to-date calculations are possible if PR is re-approved.

- May help to investigate the HT contribution to the NuTeV anomaly (model-dependent)
Overview of the Experimental Setup

Electrons detected by the two HRS independently

25-cm LD2 target (highest cooling power)

Target density fluctuation & other false asym monitored by the Luminosity Monitor

Pol e⁻ beam, 6.0 GeV, 85μA, 80%, ΔP_b/P_b = 1.0%

Beam intensity asymmetry controlled by parity DAQ

Beam Intensity asymmetry controlled by parity DAQ
In Addition to the Standard Hall A Setup

- electron method + photon integration: provide 1% precision

Also needed for PREX, HAPPEX-III, making progress now (including the upgrade to a green laser)

- 25-cm racetrack LD2 cell w/ 5mil Al endcaps

- upgrade to fast-counting DAQ, design goal: 1MHz; (scanner-based, partially w/ FADC)
E05-007 DAQ Status

- Most electronic modules purchased in FY07
- Being assembled in EEL Rm 122;
- Will install full DAQ in the right HRS for parasitic testing.
## Kinematics

<table>
<thead>
<tr>
<th>Kinematics</th>
<th>I</th>
<th>II</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X_{\text{bj}}$</td>
<td>0.25</td>
<td>0.3</td>
</tr>
<tr>
<td>$Q^2 (\text{GeV}/c)^2$</td>
<td>1.11</td>
<td>1.9</td>
</tr>
<tr>
<td>$E_{\text{beam}}$ (GeV)</td>
<td>6.0</td>
<td>6.0</td>
</tr>
<tr>
<td>$E'$ (GeV)</td>
<td>3.66</td>
<td>2.63</td>
</tr>
<tr>
<td>$\theta$ ($^\circ$)</td>
<td>12.9°</td>
<td>20.0°</td>
</tr>
<tr>
<td>$W^2 (\text{GeV})^2$</td>
<td>4.16</td>
<td>5.30</td>
</tr>
<tr>
<td>$Y$</td>
<td>0.470</td>
<td>0.716</td>
</tr>
<tr>
<td>$R_C$</td>
<td>&lt;0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>$R_S$</td>
<td>0.052</td>
<td>0.041</td>
</tr>
<tr>
<td>$R_V$</td>
<td>0.872</td>
<td>0.910</td>
</tr>
<tr>
<td>$A_d$ (measured, ppm)</td>
<td><strong>-91.3</strong></td>
<td><strong>-160.7</strong></td>
</tr>
<tr>
<td>$e^-$ rate/HRS (kHz)</td>
<td>269.8</td>
<td>25.1</td>
</tr>
<tr>
<td>$\pi/e^-$ ratio</td>
<td>0.9</td>
<td>6.4</td>
</tr>
<tr>
<td>$e^+/e^-$ ratio</td>
<td>0.073%</td>
<td>0.463%</td>
</tr>
<tr>
<td>Total rate/HRS (kHz)</td>
<td><strong>513.0</strong></td>
<td><strong>186.2</strong></td>
</tr>
</tbody>
</table>
## Expected Uncertainties on $A_d$

<table>
<thead>
<tr>
<th>Source \ $\Delta A_d/A_d$</th>
<th>$Q^2=1.1$ GeV$^2$</th>
<th>$Q^2=1.9$ GeV$^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta P_b/P_b=1%$</td>
<td>1.0%</td>
<td>1.0%</td>
</tr>
<tr>
<td>Deadtime correction</td>
<td>0.3%</td>
<td>0.3%</td>
</tr>
<tr>
<td>Target endcap contamination</td>
<td>0.4%</td>
<td>0.4%</td>
</tr>
<tr>
<td>Target purity</td>
<td>&lt;0.02%</td>
<td>&lt;0.02%</td>
</tr>
<tr>
<td>Pion background</td>
<td>&lt;0.2%</td>
<td>&lt;0.2%</td>
</tr>
<tr>
<td>Pair production background</td>
<td>&lt;0.2%</td>
<td>&lt;0.2%</td>
</tr>
<tr>
<td>Systematics</td>
<td>1.36%</td>
<td>1.36%</td>
</tr>
<tr>
<td>Statistical</td>
<td>2.11%</td>
<td>2.09%</td>
</tr>
<tr>
<td>Total</td>
<td>2.52%</td>
<td>2.49%</td>
</tr>
</tbody>
</table>

Note: now 5mil Al (was 3mil Be)
Data Analysis

- Extracting $A_d$ from data:

$$A_d = \frac{A_{raw}}{P_{beam}} + \Delta A_{EM}^{RC}$$

- Extracting $2C_{2u} - C_{2d}$ from $A_d$:

$$2C_{2u} - C_{2d} = a_2 A_d + b_2$$

$$a_2 = \frac{1}{K Q^2} \frac{5 + R_s + 4 R_c}{Y R_V}$$

$$b_2 = -\frac{2 C_{1u} (1 + R_c) - C_{1d} (1 + R_s)}{Y R_V}$$
Data Analysis (Update on EM Radiative Corrections)

- Resonance events contribute to 15%
- No reliable way to calculate PV asymmetry at low W and Q^2
- Almost impossible to calculate resonance structure
- Will measure resonance PV asymmetry to control $\Delta A_d$ below 1%.

PVDIS at 6 GeV Simulation

<table>
<thead>
<tr>
<th>Q^2 (GeV/c)²</th>
<th>W (GeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>1</td>
</tr>
<tr>
<td>0.75</td>
<td>1.5</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>1.25</td>
<td>2.25</td>
</tr>
<tr>
<td>1.5</td>
<td>2.5</td>
</tr>
<tr>
<td>1.75</td>
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</tr>
<tr>
<td>2</td>
<td>3</td>
</tr>
<tr>
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</tr>
<tr>
<td>2.5</td>
<td>3.5</td>
</tr>
<tr>
<td>2.75</td>
<td>4</td>
</tr>
</tbody>
</table>

X. Zheng, PAC33, January 2008
# Data Analysis (Update on EM Radiative Corrections)

**PVDIS at 6 GeV Simulation**

<table>
<thead>
<tr>
<th>Kine#</th>
<th>E (GeV)</th>
<th>(\theta)</th>
<th>(E') (GeV)</th>
<th>e-rate (KHz)</th>
<th>(A_d)</th>
<th>(\Delta A_d/A_d)</th>
<th>Beam time (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>4.8</td>
<td>12.5</td>
<td>4.00 (L)</td>
<td>1288</td>
<td>-68.7</td>
<td>5%</td>
<td>28.6</td>
</tr>
<tr>
<td>4</td>
<td>4.8</td>
<td>12.9</td>
<td>3.55 (L)</td>
<td>888</td>
<td>-67.7</td>
<td>5%</td>
<td>42.6</td>
</tr>
<tr>
<td>5</td>
<td>4.8</td>
<td>12.9</td>
<td>3.10 (R)</td>
<td>791</td>
<td>-60.6</td>
<td>5%</td>
<td>59.8</td>
</tr>
<tr>
<td>6</td>
<td>4.8</td>
<td>19.0</td>
<td>2.77 (R)</td>
<td>105</td>
<td>-120.7</td>
<td>8%</td>
<td>44.6</td>
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<tr>
<td>7</td>
<td>6.0</td>
<td>14.0</td>
<td>4.00</td>
<td>280</td>
<td>-113.0</td>
<td>8%</td>
<td>19.0</td>
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</table>

Note: RES beam time: 4 days

Adjusted to balance L/R HRS

\(Q^2=1.1\)

\(Q^2=1.9\)
### Expected Uncertainties on $2C_{2u} - C_{2d}$

<table>
<thead>
<tr>
<th>Source \ $\Delta(2C_{2u} - C_{2d})$</th>
<th>$Q^2=1.1$ (GeV/c)$^2$</th>
<th>$Q^2=1.9$ (GeV/c)$^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Statistical</td>
<td>0.0399</td>
<td>0.0253</td>
</tr>
<tr>
<td>Systematics (from $A_d$)</td>
<td>0.0257</td>
<td>0.0165</td>
</tr>
<tr>
<td>Experimental ($Q^2$)</td>
<td>0.0040</td>
<td>0.0017</td>
</tr>
<tr>
<td>$\Delta R = \Delta(\sigma_L/\sigma_T)$</td>
<td>0.00006</td>
<td>0.00013</td>
</tr>
<tr>
<td>Parton distribution functions</td>
<td>0.0071</td>
<td>0.0031</td>
</tr>
<tr>
<td>Electro-magnetic rad. cor.</td>
<td>0.0189</td>
<td>0.0121</td>
</tr>
<tr>
<td>Electro-weak rad. cor.</td>
<td>0.0038</td>
<td>0.0024</td>
</tr>
<tr>
<td>Higher Twist (using 1%/$Q^2$ on $A_d$)</td>
<td>0.0170</td>
<td>0.0064</td>
</tr>
<tr>
<td>CSV (MRST nominal)</td>
<td>0.0054</td>
<td>0.0031</td>
</tr>
<tr>
<td>CSV (MRST 90% C.L.)</td>
<td>0.0132</td>
<td>0.0085</td>
</tr>
<tr>
<td>Total uncertainty</td>
<td>0.0518</td>
<td>0.0329</td>
</tr>
</tbody>
</table>

*Need 42 DIS production days*

X. Zheng, PAC33, January 2008
Beam Time Request

- Commissioning: 4 days (DAQ, target/boiling test, Compton)
  could be down to 1-2 days if next to other PV experiments

- DIS Production:

<table>
<thead>
<tr>
<th>$E_b$ (GeV)</th>
<th>$\theta$ (degrees)</th>
<th>$E'$ (GeV)</th>
<th>$Q^2$ (GeV/c$^2$)</th>
<th>$e^-$ prod (days)</th>
<th>$e^+$ prod (hours)</th>
<th>Dummy (hours)</th>
<th>Total (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.0</td>
<td>12.9</td>
<td>3.66</td>
<td>1.1</td>
<td>9.0</td>
<td>4</td>
<td>3.5</td>
<td>9.3</td>
</tr>
<tr>
<td>6.0</td>
<td>20.0</td>
<td>2.63</td>
<td>1.9</td>
<td>32.0</td>
<td>4</td>
<td>12.4</td>
<td>32.7</td>
</tr>
</tbody>
</table>

- Resonance Measurement: 4 days

- Total beam time requested: 50 days
Summary – part I

- Measure PVDIS Asym. $A_d$ at $Q^2=1.10$ and $Q^2=1.90$ GeV$^2$ to $\sim 2\%$ (stat.);

- The $A_d$ at $Q^2=1.10$ GeV$^2$ will help to investigate if there are significant higher-twist effects:
  - the first limit on HT in PV DIS; might help understand other data;

- If HT is small, from $A_d$ at $Q^2=1.90$ GeV$^2$, can extract $\Delta(2C_{2u}-C_{2d}) = 0.033$;
  - factor of 7.4 improvement;
  - will provide constraints on various new physics;

- Request for 50 days;

- Compton upgrade, fast counting DAQ well under way;

- Will start/establish the PV DIS program at JLab, provide important guidance to the 12 GeV program.
Why Now, and why 50 days?

Doing PVDIS is hard, but nevertheless will have some information about PV DIS, and will be able to answer:

★ Is the HT contribution un-expectedly large? (Impacts on theories, plan for PV DIS program at 12 GeV)
★ Does it affect our interpretation of the data, and the NuTeV anomaly?

*If we don’t do it now, we will still know nothing about PV DIS;*

★ No guidance for HT theories for another decade, no guidance for the 12 GeV program;
★ At the beginning of 12 GeV, first thing to do is still to measure $A_\phi$ at low $Q^2$ (1-2 GeV$^2$, to better than 2%, using lower beam energy) to set limit on the HT.
(PR12-07-102: 0.5% at $<Q^2>$~3.2 GeV$^2$ using HMS+SHMS; or large solenoid: 1% for a wide (x,y,Q$^2$))

★ If HT is small, then we (JLab) could already make an impact on EW physics study at 6 GeV, we should do this ASAP.

This is a necessary exploratory step, yet still could make an impact (wider than medium/high energy community).
Current Knowledge on $C_{1,2q}$ (new) 

- PDG best fit
- R. Young (combined)
- MIT/Bates
- SLAC/Prescott
- Qweak (expected)
- R. Young (PVES)

This proposal (PDG fit)
This proposal (R. Young's fit)

Full beam time (50 days): $\Delta(2C_{2u} - C_{2d}) = 0.033 \rightarrow$ factor of 7.4 improvement;
New physics mass limit: 1.0 TeV.
Backup Slides
PV DIS and New Physics

\[ A_{pv} = \]

- Interaction of new physics:

\[ \mathcal{L}[V(e) \times A(q)] = \mathcal{L}_{SM}^{PV} + \mathcal{L}_{NEW}^{PV} \]

\[ \mathcal{L}_{SM}^{PV} = -\frac{G_F}{\sqrt{2}} \bar{e} \gamma_\mu e \sum_q \mathcal{C}_{2q} \bar{q} \gamma^\mu \gamma^5 q \]

\[ \mathcal{L}_{NEW}^{PV} = \frac{g^2}{4 \Lambda^2} \bar{e} \gamma_\mu e \sum_f h_{q_f}^q \bar{q} \gamma^\mu \gamma^5 q \]

- \( g \): coupling constant; \( \Lambda \): mass scale, \( h_{q_f}^q \): effective coefficients;

- Sensitive to: \( Z' \) searches, compositeness, leptoquarks

- Mass limit of the proposed measurement:

\[ \frac{\Lambda}{g} \approx \frac{1}{\sqrt{8 G_F \Delta (2 C_{2u} - C_{2d})}} \approx 1.0 \text{ TeV} \]

- Some new physics can affect \( C_2 \), but not \( C_1 \).
PV DIS and New Physics (a few examples)

- **Z' Searches**: will give $M_{Z'} = 0.8 \text{ TeV (1}\sigma\text{), or 450 GeV (90\% C.L.)};$

- **Compositeness (8 four-fermion contact interactions)**:
  - SU(12): affect $C_{2q}$ but not $C_{1q}\rightarrow C_{2q}$ provide a unique opportunity to explore quark and lepton compositeness;
  - Will give $\Lambda_1 = 3.56 \text{ TeV (1}\sigma\text{), or 1.97 \text{ TeV (90\% C.L.)};}$
  - Provide important inputs for fitting all contact terms simultaneously.

- **Leptoquarks**: for a scalar LQ interacting with $u$ quarks, will give
  
  $$\Lambda_s < 0.14 \ (M_{LQ}/100 \text{ GeV})$$

  (comparable to the Cs APV experiment)
Status of CSV Calculations

Latest MRST fit:

\[ u_v^n(x) = d_v^p(x) + \kappa f(x) \quad d_v^n(x) = u_v^p(x) + \kappa f(x) \]

nominal: \[ \kappa = 0.20 \quad \delta = 0.08 \]

\[ u_{sea}^n(x) = d_{sea}^p(x)(1 + \delta) \quad d_{sea}^n(x) = u_{sea}^p(x)(1 + \delta) \]

90% C.L.: \[ \kappa = (-0.80, 0.65) \quad \delta = (-0.08, 0.18) \]


CSV from MRST2003c Fit, \( Q^2 = 1.00 \text{ GeV}^2 \)

CSV from MRST2003c Fit, \( Q^2 = 2.00 \text{ GeV}^2 \)

max at 90% C.L.

min at 90% C.L.

proposed \( Q^2 = 1.1 \)

(90\% C.L. \( \sim 1/2 \) of \( \Delta A_{\text{stat}} \))

proposed \( Q^2 = 1.9 \)

X. Zheng, PAC33, January 2008
Electroweak Radiative Corrections to $C_{2u}$ and $C_{2d}$

Studied originally in the context of Atomic Parity Violation, well understood.

Marciano and Sirlin, PRD 27, 552 (1983)
Marciano, "Radiative Corrections to Neutral Current Processes" from Precision Tests of the Standard Model edited by Langacker

Numerical values from PDG

Small effect for PVDIS

$A_d$ correction
2.2% ($Q^2 = 1.1$) and
2.6% ($Q^2 = 1.9$)

$\Delta A_d < 0.3\%$

$C_{1u} = \rho'_{eq} \left( -\frac{1}{2} + \frac{4}{3} \tilde{\kappa}'_{eq} \hat{s}_Z^2 \right) + \lambda_{1u}$

$C_{1d} = \rho'_{eq} \left( \frac{1}{2} + \frac{2}{3} \tilde{\kappa}'_{eq} \hat{s}_Z^2 \right) + \lambda_{1d}$

$C_{2u} = \rho_{eq} \left( -\frac{1}{2} + 2 \tilde{\kappa}_{eq} \hat{s}_Z^2 \right) + \lambda_{2u}$

$C_{2d} = \rho_{eq} \left( \frac{1}{2} - 2 \tilde{\kappa}_{eq} \hat{s}_Z^2 \right) + \lambda_{2d}$

Box diagrams

$\kappa - \gamma-Z$ mixing

X. Zheng, PAC33, January 2008
Design and Structure for the Fast Counting DAQ

- Using
  - A double-layered lead-glass counter, summed by 8-block groups
  - A gas cherenkov detector
  - Scintillator signals to suppress background
  - Discriminators and logic modules to choose $e^-$ and $\pi$, two time windows (100 and 20 ns)
  - Helicity-gated scalers to count $e^-$ and $\pi$ (15 subgroups + “OR”ed)

- Some channels with FADC, allowing full sampling of signals

- All detector signals passively splitted, allowing parasite, non-invasive testing

- Deadtime measured by multiple methods
## Physics Outcome from Reduced Beam Time

<table>
<thead>
<tr>
<th>Production time (days)</th>
<th>( \Delta A_d / A_d )</th>
<th>( \Delta(2C_{2u} - C_{2d}) ) (Q(^2)=1.9)</th>
<th>Total (days)</th>
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PAC27 report: “The experiment appears feasible and the running time can be divided readily into two phases as described in the proposal.”
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“Two phases running”, not “two phases beam time approval”
## Physics Outcome from Reduced Beam Time

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</tbody>
</table>

- way above expectation for HT
- 2 years of preparation for 9 production days
Rescattering Background

Effect depends on:

- How many particles will be re-scattered? — 1% near central momenta, mostly from the Q3 exit (studied by HAPPEX-H and HAPPEX-He).

- Whether these events carry different asymmetries? — Unlikely, most have DIS kinematics very close to central setting

- Expect an effect on $A_d$ at the $10^{-3}$ level.

Will take data at low rate and compare with simulation to pin down the effect.
Deuteron EMC Effect?

Calculations show very small effect on $F_2^d$: $(1.2\pm0.5)\%$ for $x=0.25$ and $(1.5\pm0.6)\%$ for $x=0.3$.

W. Melnitchouk, A.W. Thomas, nucl-th/9603021

Effect on the asymmetry should be much smaller – $2\times10^{-4}$ on $A_d$ using the smearing technique:

$$q^D(x) = \int_x^1 dy f_{N/D}(y) q^N(x/y)$$
Status of HT Calculations

- MIT Bag Model I: 0.3%/\(Q^2\)
- MIT Bag Model II: <2%/\(Q^2\)
- Calculation using \(C_{HT}\) from \(F_{1,2}\) data: <1%/\(Q^2\) for 0.1<x<0.3

HT likely to be small at \(Q^2=2\ (\text{GeV}/c)^2\), nevertheless, will measure \(A_d\) at 1.1 (GeV/c)^2 to check

More up-to-date calculations are possible if PR is re-approved.

May help to investigate the HT contribution to the NuTeV anomaly (model-dependent):

- A 3% HT contribution to \(\sin^2\theta_W\) from \(A_d\) at \(Q^2=2\ (\text{GeV}/c)^2\) implies the same size (3%) of correction to the NuTeV P-W ratio;
  

- If the HT correction is 2.5% in the P-W ratio (the NuTeV anomaly has its P-W ratio 2.5% from the SM) \(\rightarrow\) 5% on our \(A_d\) at \(Q^2=1.9\ (\text{GeV}/c)^2\) and 8% at \(Q^2=1.1\ (\text{GeV}/c)^2\)
Advantages of “Two Phases” Running

- The expected results from the first phase running (13 days) are
  - $5\%/Q^2$ on the HT in PV (first limit);
  - $\Delta(2C_{2u}-C_{2d}) = 0.066$ (factor of 3.5 improvement);
  - Already significant.

- Results of the first phase running will provide guidance for beam time allocation during the second phase
  - Minimize impacts of possible instrumentalational problem on the final results.
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- Minimize impacts of possible instrumentalational problem on the final results.
Experimental Hall A
An alternative option (LOI03-106): Scaler-Logic-based Fast Counting DAQ
E-158 Möller

NuTeV

QWeak

APV Cs

DISParity

JLab

12 GeV

A_{fb}

\sin^2(\theta_W)

\begin{align*}
\text{MS-bar scheme} \\
\text{Erler and Ramsey-Musolf} \\
\text{Phys. Rev. D72 073003 (2005)}
\end{align*}

Q (GeV)

10^{-4} \quad 10^{-3} \quad 10^{-2} \quad 10^{-1} \quad 1 \quad 10 \quad 10^2 \quad 10^3 \quad 10^4
New Physics Reach: $Q_{\text{weak}}$ and Møller

\[ \delta \left( \frac{Q_W^e}{Q_W^e} \right)_{\text{SUSY}} / \left( \frac{Q_W^e}{Q_W^e} \right)_{\text{SM}} \]

- RPV SUSY (no SUSY Dark Matter)
- Future 2.5% $Q_W^e$ and Møller
- 4% $Q_W^e$ Measurement
- Future 2.5% $Q_W^e$ and Møller
- RPC SUSY
Add data on PVDIS: ± 1.0%
Two Photon Exchange Effect?

- TPE contribute to <1% of cross section for $1 < Q^2 < 2 (\text{GeV}/c)^2$

  “Two-Photon Exchange in Electron-Deuteron Scattering”,

- Effect on the asymmetry should be even smaller.