JLab 6 GeV PVDIS

Ramesh Subedi
George Washington University

for

Xiaoyan Deng\textsuperscript{1}, Robert Michaels\textsuperscript{2}, Paul Reimer\textsuperscript{3}, Diancheng Wang\textsuperscript{1}, Xiaochao Zheng\textsuperscript{1}

\textsuperscript{1} University of Virginia, \textsuperscript{2} Jefferson Lab, \textsuperscript{3} Argon National Laboratory

MENU2010: May 31 - June 4, 2010
College of William and Mary, Williamsburg, Virginia

June 2, 2010
The electroweak interaction is Parity Violating as it changes sign if we flip the spin of the incoming electron beam. The study of such interaction in a Deep Inelastic Scattering region is PVDIS.

If we measure two mirror-image scattering processes in the same experimental conditions, the difference between the two counting rates can isolate the weak contribution. In practice, we measure the ratio of the difference over the sum which cancels out all the errors of normalization and allows accurate measurement of small quantities.

\[ A_{\text{expt}} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} \equiv Q^2 [100 \, \text{ppm/GeV}^2] \]

- \( A_{\text{expt}} \): Experimental parity violating asymmetry
- \( \sigma_R \): Right handed helicity electron cross section
- \( \sigma_L \): Left handed helicity electron cross section
With $M_\gamma$ and $M_Z$ being the electromagnetic and weak amplitudes corresponding to $\gamma$ and $Z$ exchange, respectively,

$$\sigma \propto |M_\gamma + M_Z|^2.$$  The interference term violates the parity and this term is immensely small too, because of a large $M_\gamma$ value multiplied by a small $M_Z$ value. The order of magnitude of the electroweak interference is:

$$A_{pv} \sim \frac{M_\gamma M_Z}{|M_\gamma|^2} \sim \frac{M_Z}{M_\gamma} \sim 10^{-4} Q^2 \text{ GeV}^2/c^2.$$

The actual theoretical expression for the asymmetry $A_{pv}$ for the PVDIS experiment will be given in a later slide.

$A_{expt}/P_e = A_{pv}$ is the link between experiment and theory, where $P_e$ is the magnitude of electron beam polarization.
In PVDIS experiment, we are trying to measure the strength of the parity violation in DIS region by measuring an asymmetry and use this asymmetry to extract other quantities.

In the past, there has been only one PVDIS expt, E122, at SLAC in 1970’s using a polarized electron beam on an unpolarized deuterium target. It measured $\sin^2 \theta_w$ which provided one of the first tests for the Standard Model. In about 4 decades later: PVDIS at JLab.

Unlike other parity violating experiments, PVDIS has access to the coupling constant $C_{2q}$ with a possibility of factor $\sim 5$ improvement. It will also study hadronic (higher twist) effects. Both of these quantities are important in studying electroweak Standard Model.

Most of the tools developed during this expt can be adopted in the 12 GeV PVDIS.
The goal of the experiment is to measure the parity violating asymmetry to a 3% (stat.) precision at two $Q^2$ points.

- $Q^2 = 1.11 \text{ (GeV/c)}^2$: $\theta = 12.9^\circ$, $E = 6.0$ GeV, $E' = 3.66$ GeV, $x_B = 0.25$, $W^2 = 4.16 \text{ (GeV)}^2$.
- $Q^2 = 1.90 \text{ (GeV/c)}^2$: $\theta = 20.0^\circ$, $E = 6.0$ GeV, $E' = 2.63$ GeV, $x_B = 0.30$, $W^2 = 5.30 \text{ (GeV)}^2$.

To extract other quantities, the following tools were used:
- Taking 100 $\mu$A beam at 6 GeV with 88% beam polarization on a 20 cm liquid deuterium target.
- Using both high resolution spectrometers (HRS) in hall A for an independent detection of scattered electrons.
- Developing and implementing new counting DAQs in both HRSs having hardware based PID with the event rate handling capability upto 1 MHz.
- Full event information sampled at lower rates by HRS DAQs for each kinematics, efficiencies and PID analysis.
- The timing alignment of the detector signals was performed by using FASTBUS TDCs and monitored continuously using the HRS DAQ.
Using the measured asymmetry we can investigate:

- coupling constant combination \((2C_{2u} - C_{2d})\) as shown in the next slide.
- hadronic correction, \(C'(x)\), from higher-twist (HT) effects:
  \[
  A_{\text{exp}}(x, Q^2) = A_{\text{exp}}(x)(1 + C(x)/Q^2).
  \]
  From \(Q^2=1.11 \text{ (GeV/c)}^2\) we can investigate if there are significant HT effects – a “Baseline” measurement for the future 12 GeV PVDIS program.

- If HT is small, from \(Q^2=1.90 \text{ (GeV/c)}^2\) we can extract \(2C_{2u} - C_{2d}\) to about a factor of 5 improvement.

This experiment will serve as an exploratory step for the 12-GeV PVDIS program.
The important outcome of the experiment will be the extraction of 
\((2C_{2u} - C_{2d})\), shown in Eqn.(1), with a high precision.

\[
A_{pv} = \left( \frac{3G_F Q^2}{\pi \alpha^2 \sqrt{2}} \right) \frac{2C_{1u}[1 + R_C(x)] - C_{1d}[1 + R_S(x)] + Y (2C_{2u} - C_{2d}) R_V(x)}{5 + R_S(x) + 4R_C(x)}
\]  

(1)

with effective coupling constants \(C_{1,2q}\):

\[
C_{1u} = g_e^u g_v^u = -\frac{1}{2} + \frac{3}{4} \sin^2(\theta_w) \sim -0.19,
\]

(2)

\[
C_{1d} = g_e^d g_v^d = \frac{1}{2} - \frac{2}{3} \sin^2(\theta_w) \sim 0.34,
\]

(3)

\[
C_{2u} = g_v^u g_a^u = -\frac{1}{2} + 2 \sin^2(\theta_w) \sim -0.04,
\]

(4)

\[
C_{2d} = g_v^d g_a^d = \frac{1}{2} - 2 \sin^2(\theta_w) \sim 0.026,
\]

(5)

where \(C_{1u(d)}\) represents the axial Z-electron coupling \(g_a^e\) times the vector Z-u(d) quark coupling \(g_v^u(d)\), and the \(C_{2u(d)}\) is the vector Z-electron coupling \(g_v^e\) times the axial Z-u(d) quark coupling \(g_a^u(d)\). \(G_F\) is the Fermi weak coupling constant, \(Y\) is kinematical factor, \(R_C\), \(R_S\) and \(R_V\) being sea- and valence- quark distribution functions (see proposal E08-011 for detail).
Current (2008) experimental knowledge of $C_{2q}$. The PVDIS band passes through the best-fit central value of PDG (also R. Young et al.).
Overview of the Experimental Setup

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

Pol e\textsuperscript{-} beam, 6.0 GeV, 85\textmu{}A, 80\%, \Delta P_b/P_b = 1.0\%

Beam intensity asymmetry controlled by parity DAQ

20 cm LD2
Some highlights of the PVDIS experiment

- Took high rate data (electrons, pions): \( \sim 400 \text{ kHz per arm.} \)
- No use of *integrating DAQ*, as used by other parity violating expts at JLab, since electrons and pions had to be identified.
- Developed/used a *scanner based counting DAQ* with electron and pion PID for the first time in Hall A. Found no issue.

- Used a 10 kHz pulser as a tagger to determine deadtime. Diancheng Wang will talk on tagger result later.
- Routinely monitored: beam polarization (using Moller: polarization \( \sim 88\% \)), and the PID efficiency. The Compton polarimeter was also continuously operational but not fully understood the electron detection part.
- Took Flash ADC data, it will be analyzed for pileup.

For background checks:
- A continuous monitoring of target noise using lumi and beam charge asymmetry controlled by a feedback loop.
- Took aluminum dummy data, and also *positron data* on the aluminum dummy. Rates agree with calculations.
- Measured transverse beam polarization, found to be \(< 2\%\).
Like every other experiments, we also had some minor problems:

- Had to use a 20 cm liquid deuterium target instead of a 25 cm one as said in the proposal.
- Though the 4-day PVDIS commissioning was supposed to start on Oct 30, 2009, we took production beam only on Nov 8, 2009 due to the spectrometer magnet problems (right $Q^2$ came back online on Nov 6th).
- Spectrometer motion had to be done by hand held drills: hours of overhead for rotation by even about a degree. To move both spectrometers, we had to go to “restricted access” due to a need of a dozen people.
- Due to the Central Helium Liquifier (CHL) crash, we lost target for about 26 hours (Dec 19-20) in about the end of the run-period.

Despite such problems, obtaining a higher beam current of $>100\mu\text{A}$, instead of $85\mu\text{A}$ as in the proposal, compensated the experiment’s need of luminosity.
Data check: asymmetry from left arm at $Q^2=1.1\text{ GeV}^2/c^2$, $P_0=3.66\text{ GeV}^2/c^2$

HWP OUT, asym = 62.8 +/- 4.1(ppm)

HWP IN, asym = -61.4 +/- 3.9(ppm)

A slug has 1 M pairs of events collected in about 24 hours of time.
Data check: asymmetry from left arm at $Q^2 = 1.9 \text{ GeV}^2/c^2$, $P_0 = 2.63 \text{ GeV}^2/c^2$

HWP OUT, asym = $142.7 \pm 16.6(\text{ppm})$

HWP IN, asym = $-116.0 \pm 14.6(\text{ppm})$
Data check: asymmetry from right arm at $Q^2=1.9 \text{ GeV}^2/c^2$, $P_0=2.63 \text{ GeV}^2/c^2$

Analysis for deadtime, BCM calibration, Compton analysis, and simulations being tackled at moment (see talks from Dianchang and Xiaoyan).
Conclusion

- Implemented a scaler based counting DAQ.
- Successfully finished data taking in Dec’09 in a quality-controlled way with a robust online monitoring scheme.
- The Compton polarimetry was not as good as expected, but a careful analysis could meet expectation: 2% accuracy in electron beam polarization. This may not be an issue since the statistical accuracy of data may not be below 3%.
- Offline data analysis is underway.
Memorable Event

Both spectrometers had to be moved by hand held drills, 8 persons with one drill each, per spectrometer. Moving by about 7° would take several hours.
Error on physics asymmetry

<table>
<thead>
<tr>
<th>Source \ $\Delta A_d/A_d$</th>
<th>$Q^2=1.1\text{ GeV}^2$</th>
<th>$Q^2=1.9\text{ GeV}^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta P_b/P_b=1%$</td>
<td>2.0%</td>
<td>2.0%</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>2.08%</td>
<td>2.08%</td>
</tr>
<tr>
<td>Statistical</td>
<td>3.0%</td>
<td>4.0%</td>
</tr>
<tr>
<td>Total</td>
<td>3.7%</td>
<td>4.5%</td>
</tr>
</tbody>
</table>